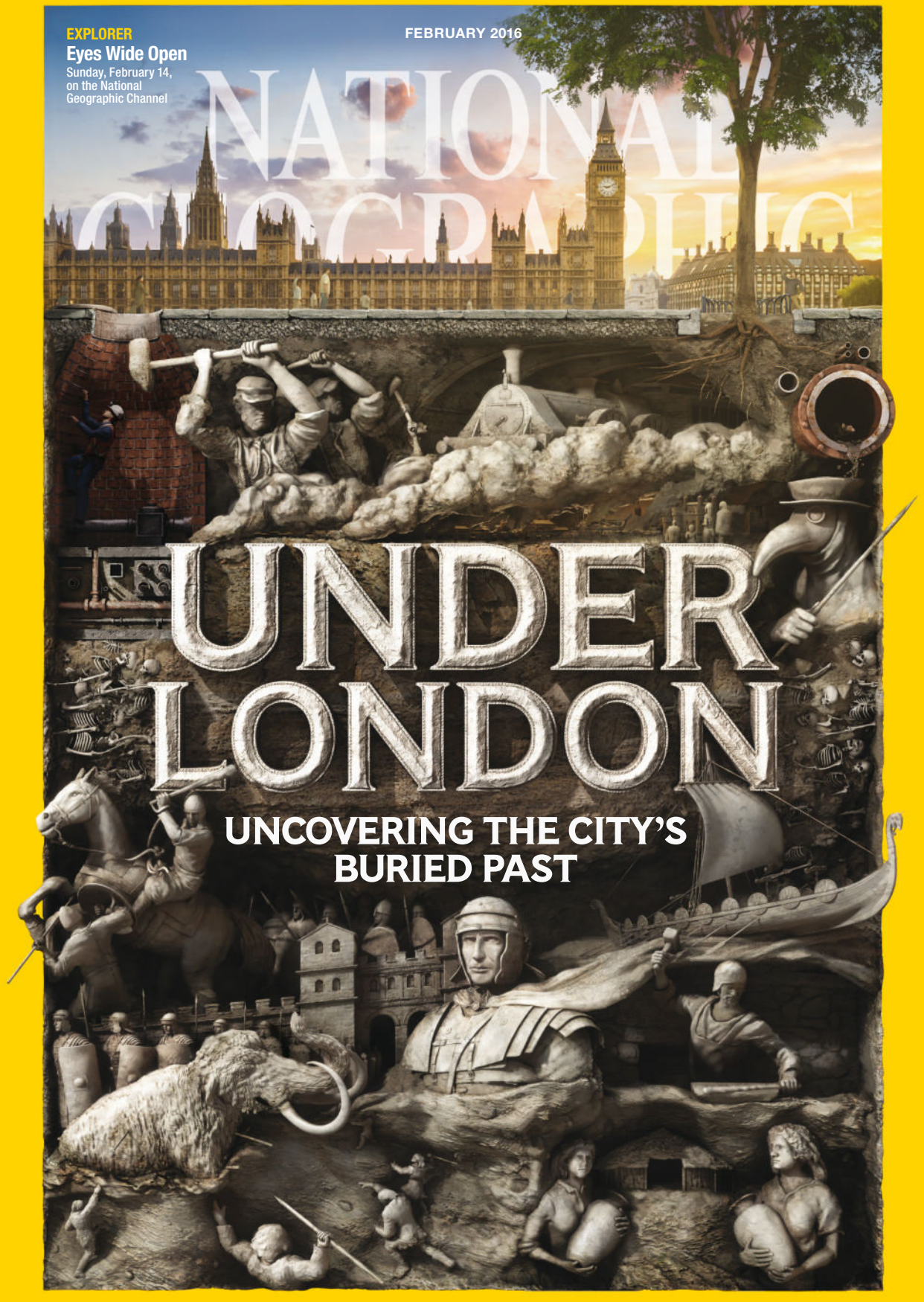
FEBRUARY 2016

EXPLORER
Eyes Wide Open
Sunday, February 14,
on the National
Geographic Channel



UNDER LONDON

UNCOVERING THE CITY'S BURIED PAST

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Plastic bottles. Disposable forks. Single-serving containers. If there's anything we humans like, it's convenience. Unfortunately, the easy way is having unforeseen consequences in our National Parks. Each year, visitors to these incredible places generate over 100 million pounds of garbage that ends up buried in our nation's landfills. The good news is that, just like Subaru did over a decade ago, we believe we can work toward making the parks zero landfill. With a little more effort, the environmental expertise of Subaru, and the dedication and passion of the National Park Service and National Parks Conservation Association, we have a real chance to make history in these irreplaceable treasures.

Get involved, and see the ongoing documentary series at subaru.com/environment.

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NATIONAL GEOGRAPHIC

FEBRUARY 2016 • VOL. 229 • NO. 2

A grizzly bear eats a ground squirrel—one of the many edibles available to the omnivore in Denali National Park and Preserve.

Smashing Stereotypes

What is life like for women in the most profoundly gender-segregated nation on Earth at a time of fraught change? This was the question that drew two extraordinary journalists—photographer Lynsey Addario and writer Cynthia Gorney—to an in-depth reporting assignment in Saudi Arabia.

They returned with answers that show the tyranny of assumptions. Instead of victims beneath black veils, Addario and Gorney met warm, articulate women willing to invite them into their homes and talk about their experiences; women who joke, complain, express anger—and smash to smithereens the stereotype of the silenced Saudi woman.

Founded in 2006, Jeddah United was the first Saudi sports league to train and manage athletes of both genders. Above, members of its women's basketball team practice.

"I found women willing to argue energetically with me, and with each other, about almost everything," says Gorney, including "women's new expectations in the workplace, whether gender-separating rules ought to change in the modernizing nation, and whether a woman's dignity does or does not demand keeping her face covered in public."

These revelations come to life in Addario's photos, which depict professional, fashionable, tech-savvy women—images missing from typical coverage of women in the Desert Kingdom.

A constricted life persists. As Gorney says, "the litany of 'only nation in the world' rules in Saudi Arabia is familiar by now: The only nation in the world that prohibits women from driving cars. The only nation that requires every adult female citizen to live under the supervision of a legally recognized male guardian... The last nation, other than Vatican City, to grant women the vote."

To Americans, pretty much everything about this picture seems wrong. But as the superb reporting in this issue makes clear, we'd be mistaken to assume that Saudi women want precisely our lives or our version of freedom and empowerment.

National Geographic is known for taking readers to places they have never seen, places they may never go. "The Changing Face of Saudi Women" is that kind of piece—a journey through a complex, hidden realm that yields a deeper understanding and appreciation of the world beyond the headlines.

Susan Goldberg, *Editor in Chief*

For more of Lynsey Addario's photos illuminating the lives of Saudi women, go to *nationalgeographic.com.*

PHOTO: LYNSEY ADDARIO

Cape Gannet *(Morus capensis)*
Size: Body length, 85 - 90 cm (33.5 - 35.5 inches) **Weight:** Approx. 2.6 kg (5.7 lb) **Habitat:** Southern Africa's coasts; breeds on only six islands **Surviving number:** Estimated at 150,000 breeding pairs

Photographed by Tom Walmsley

WILDLIFE AS CANON SEES IT

Dive master. When seeking prey, the cape gannet hurls itself toward the water, losing hardly any speed as it submerges. It spends some 20 seconds underwater on each dive hunting pilchard, sauries and anchovies. To conserve energy, the bird then uses its natural buoyancy to rise to the surface. But food sources are disappearing due to commercial overfishing. The cape gannet has also run afoul of oil spills, and competition is increasing with other species for habitat on its breeding islands. This all adds up to deep trouble.

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.

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NATIONAL GEOGRAPHIC

We believe in the power of science, exploration, and storytelling to change the world.

The National Geographic Society is a global nonprofit membership organization. We inspire through exploration, illuminate through stories, and, always, teach.

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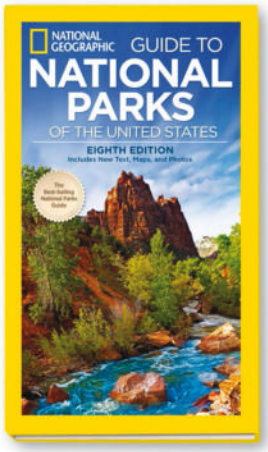
One hundred years ago, National Geographic helped persuade the U.S. government to create the National Park Service. Today National Geographic is the world's #1 resource for national parks content and products and is dedicating an entire year, across all its global platforms, to focus on the importance of these irreplaceable places and encourage people to explore, experience, understand, and preserve them. Parks are more critical than ever to ensure the health and sustainability of our planet: they connect us with the natural world and inspire us all to be better stewards of our only home.



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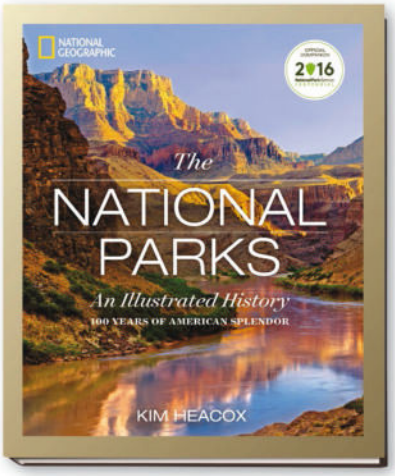
—**Examiner.com**



NATIONAL GEOGRAPHIC

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Did You Hear the One About the Neanderthal?

Ella Al-Shamahi may be the rarest kind of paleoanthropologist—the kind who also performs stand-up comedy. Al-Shamahi, a 31-year-old National Geographic emerging explorer, digs for fossils in the Middle East. Her goal? To understand the serious business of Neanderthal evolution and migration. She also performs regularly in London.

Science and comedy. How does that work?
Well, when you think about it, we have a communication problem in science. We see massive cuts in research funding and science education. How do we get to people who are uninterested? How do we engage young girls who have no interest in the subject whatsoever? I think comedy is the next stage in the evolution of how we present science.

You're a woman in science doing work in unstable places. That doesn't sound like it's always funny.
I'm the stereotype of the comic who does comedy because she needs to laugh. Some places where I research are quite dark. It's incredible therapy to find the funny in it. The stage is an escape. There's an entertainment component, but it's also very selfish. You're escaping from the formalities of life and data. You can be ridiculous. People let you be ridiculous because the places you take them can be very fun.

How about an example?
Ooh... You can't just ask somebody for their best punch lines! I did have this one: People were asking me whether Neanderthals had culture—and I'm like, Of course! Most of them live in museums. [Pause] That's a terrible joke. But it gets people thinking. Another time, a professor was misquoted as seeking an adventurous female to become pregnant with a cloned Neanderthal. It occurred to me that if I, as a female Neanderthal specialist, had this kid, it would be the only time when having a child actually helped a woman's career.

PHOTO: PETER DENCH, GETTY IMAGES

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VISIONS

Poland
Seen from the Grunwaldzki Bridge in Kraków, a winter scene offers a yin-yang study in contrasts. On the snowy banks of the Vistula River, a silhouetted figure feeds white swans and dark-plumed ducks and coots in the frigid water.

PHOTO: MARCIN RYCZEK

Poland
On the wintry Vistula Spit—a sandy, wind-carved peninsula near Kaliningrad, a Russian province—a tractor pulls sledders across the snow-white expanse. The spit juts into the Baltic Sea, separating the Gulf of Gdańsk from the Vistula Lagoon.

PHOTO: KACPER KOWALSKI, PANOS

Germany
A lone cross-country skier near Masserberg traverses the Rennsteig, an ancient ridgeway. The roughly 105-mile-long hiking trail—a messenger route in the Middle Ages—runs west to east through the Thuringian Forest.

PHOTO: MARTIN SCHUTT, EPA

For people with a higher risk of stroke due to
Atrial Fibrillation (AFib) not caused by a heart valve problem

ELIQUIS® (apixaban) is a prescription medicine used to reduce the risk of stroke and blood clots in people who have atrial fibrillation, a type of irregular heartbeat, not caused by a heart valve problem.

IMPORTANT SAFETY INFORMATION:

- **Do not stop taking ELIQUIS for atrial fibrillation without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke.** ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.
- **ELIQUIS can cause bleeding, which can be serious,** and rarely may lead to death.
- **You may have a higher risk of bleeding if you take ELIQUIS and** take other medicines that increase your risk of bleeding, such as aspirin, NSAIDs, warfarin (COUMADIN®), heparin, SSRIs or SNRIs, and other blood thinners. **Tell your doctor about all medicines, vitamins and supplements you take.**

While taking ELIQUIS, you may bruise more easily and it may take longer than usual for any bleeding to stop.

- Get medical help right away if you have any of these signs or symptoms of bleeding:
  - unexpected bleeding, or bleeding that lasts a long time, such as unusual bleeding from the gums; nosebleeds that happen often, or menstrual or vaginal bleeding that is heavier than normal
  - bleeding that is severe or you cannot control
  - red, pink, or brown urine; red or black stools (looks like tar)
  - coughing up or vomiting blood or vomit that looks like coffee grounds
  - unexpected pain, swelling, or joint pain; headaches, feeling dizzy or weak
- **ELIQUIS is not for patients with artificial heart valves.**

Now I'm going for something better than warfarin. ELIQUIS.

Reduced the risk of stroke better than warfarin.

ELIQUIS® (apixaban)

Had significantly less major bleeding than warfarin.

No routine blood testing.

ELIQUIS and other blood thinners increase the risk of bleeding which can be serious, and rarely may lead to death.

Ask your doctor if switching to ELIQUIS is right for you.

- **Spinal or epidural blood clots (hematoma).** People who take ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis). This risk is higher if, an epidural catheter is placed in your back to give you certain medicine, you take NSAIDs or blood thinners, you have a history of difficult or repeated epidural or spinal punctures. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.
- **Before you take ELIQUIS,** tell your doctor if you have: kidney or liver problems, any other medical condition, or ever had bleeding problems. Tell your doctor if you are pregnant or breastfeeding, or plan to become pregnant or breastfeed.
- **Do not take ELIQUIS if you** currently have certain types of abnormal bleeding or have had a serious allergic reaction to ELIQUIS.

A reaction to ELIQUIS can cause hives, rash, itching, and possibly trouble breathing. Get medical help right away if you have sudden chest pain or chest tightness, have sudden swelling of your face or tongue, have trouble breathing, wheezing, or feeling dizzy or faint.

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch, or call 1-800-FDA-1088.

Please see additional Important Product Information on the adjacent page.

Individual results may vary.

Learn about savings and offers.

Visit ELIQUIS.COM or call 1-855-ELIQUIS

Eliquis®
(apixaban) tablets 5mg 2.5mg

IMPORTANT FACTS about ELIQUIS® (apixaban) tablets

℞ ONLY

The information below does not take the place of talking with your healthcare professional. Only your healthcare professional knows the specifics of your condition and how ELIQUIS may fit into your overall therapy. Talk to your healthcare professional if you have any questions about ELIQUIS (pronounced ELL eh kwiss).

What is the most important information I should know about ELIQUIS (apixaban)?

For people taking ELIQUIS for atrial fibrillation: Do not stop taking ELIQUIS without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke. ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.

ELIQUIS can cause bleeding which can be serious, and rarely may lead to death. This is because ELIQUIS is a blood thinner medicine that reduces blood clotting.

You may have a higher risk of bleeding if you take ELIQUIS and take other medicines that increase your risk of bleeding, such as aspirin, nonsteroidal anti-inflammatory drugs (called NSAIDs), warfarin (COUMADIN®), heparin, selective serotonin reuptake inhibitors (SSRIs) or serotonin norepinephrine reuptake inhibitors (SNRIs), and other medicines to help prevent or treat blood clots.

Tell your doctor if you take any of these medicines. Ask your doctor or pharmacist if you are not sure if your medicine is one listed above.

While taking ELIQUIS:

- you may bruise more easily
- it may take longer than usual for any bleeding to stop

Call your doctor or get medical help right away if you have any of these signs or symptoms of bleeding when taking ELIQUIS:

- unexpected bleeding, or bleeding that lasts a long time, such as:
  - unusual bleeding from the gums
  - nosebleeds that happen often
  - menstrual bleeding or vaginal bleeding that is heavier than normal
- bleeding that is severe or you cannot control
- red, pink, or brown urine
- red or black stools (looks like tar)
- cough up blood or blood clots
- vomit blood or your vomit looks like coffee grounds
- unexpected pain, swelling, or joint pain
- headaches, feeling dizzy or weak

ELIQUIS (apixaban) is not for patients with artificial heart valves.

Spinal or epidural blood clots (hematoma). People who take a blood thinner medicine (anticoagulant) like ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis). Your risk of developing a spinal or epidural blood clot is higher if:

- a thin tube called an epidural catheter is placed in your back to give you certain medicine
- you take NSAIDs or a medicine to prevent blood from clotting
- you have a history of difficult or repeated epidural or spinal punctures
- you have a history of problems with your spine or have had surgery on your spine

If you take ELIQUIS and receive spinal anesthesia or have a spinal puncture, your doctor should watch you closely for symptoms of spinal or epidural blood clots or bleeding. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.

What is ELIQUIS?

ELIQUIS is a prescription medicine used to:

- reduce the risk of stroke and blood clots in people who have atrial fibrillation.
- reduce the risk of forming a blood clot in the legs and lungs of people who have just had hip or knee replacement surgery.

(Continued on adjacent page)

- treat blood clots in the veins of your legs (deep vein thrombosis) or lungs (pulmonary embolism), and reduce the risk of them occurring again.

It is not known if ELIQUIS is safe and effective in children.

Who should not take ELIQUIS (apixaban)?

Do not take ELIQUIS if you:

- currently have certain types of abnormal bleeding
- have had a serious allergic reaction to ELIQUIS. Ask your doctor if you are not sure

What should I tell my doctor before taking ELIQUIS?

Before you take ELIQUIS, tell your doctor if you:

- have kidney or liver problems
- have any other medical condition
- have ever had bleeding problems
- are pregnant or plan to become pregnant. It is not known if ELIQUIS will harm your unborn baby
- are breastfeeding or plan to breastfeed. It is not known if ELIQUIS passes into your breast milk. You and your doctor should decide if you will take ELIQUIS or breastfeed. You should not do both

Tell all of your doctors and dentists that you are taking ELIQUIS. They should talk to the doctor who prescribed ELIQUIS for you, before you have **any** surgery, medical or dental procedure. **Tell your doctor about all the medicines you take, including** prescription and over-the-counter medicines, vitamins, and herbal supplements. Some of your other medicines may affect the way ELIQUIS works. Certain medicines may increase your risk of bleeding or stroke when taken with ELIQUIS.

How should I take ELIQUIS?

Take ELIQUIS exactly as prescribed by your doctor. Take ELIQUIS twice every day with or without food, and do not change your dose or stop taking it unless your doctor tells you to. If you miss a dose of ELIQUIS, take it as soon as you remember, and do not take more than one dose at the same time.

Do not run out of ELIQUIS (apixaban). Refill your prescription before you run out. When leaving the hospital following hip or knee replacement, be sure that you will have ELIQUIS available to avoid missing any doses. **If you are taking ELIQUIS for atrial fibrillation, stopping ELIQUIS may increase your risk of having a stroke.**

What are the possible side effects of ELIQUIS?

- See **"What is the most important information I should know about ELIQUIS?"**
- ELIQUIS can cause a skin rash or severe allergic reaction. Call your doctor or get medical help right away if you have any of the following symptoms:
  - chest pain or tightness
  - swelling of your face or tongue
  - trouble breathing or wheezing
  - feeling dizzy or faint

Tell your doctor if you have any side effect that bothers you or that does not go away.

These are not all of the possible side effects of ELIQUIS. For more information, ask your doctor or pharmacist.

Call your doctor for medical advice about side effects. You may report side effects to FDA at 1-800-FDA-1088.

This is a brief summary of the most important information about ELIQUIS. For more information, talk with your doctor or pharmacist, call 1-855-ELIQUIS (1-855-354-7847), or go to www.ELIQUIS.com.

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Mother and Child

Assignment We asked Your Shot members to capture images of one of the closest human bonds. See more photos online.

EDITOR'S NOTE

'Great photographs show not only what something looks like but also what it feels like for the subject in that particular moment.'

Stephanie Sinclair, National Geographic photographer

Morgan Lee Curoopen
Bari, Italy

While on vacation in Mauritius, Curoopen shared a bus ride with a mother and her young son. As it thundered outside, Curoopen waited for a bright background—a yellow and red storefront—to take a photo.


HOW FAR WILL YOU TAKE IT
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With spacious cargo capacity* and standard All-Wheel Drive with intelligence (AWD-i).
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Let's Go Places
Prototype shown with options. Production model may vary. *Cargo and load capacity limited by weight and distribution. ©2015 Toyota Motor Sales, U.S.A., Inc.

EXPLORE

Us

King of the Canines

Uneasy lies the head that wears a crown—even if that head belongs to a Labrador retriever chasing a tennis ball in a swimming pool. For the past 24 years the American Kennel Club (AKC) has proclaimed Labradors the most popular dogs in the United States, based on the number of dogs registered with the organization. But just ask English setters—number one in the 1880s, now 87th out of 187 breeds—how fickle fame can be.

What predicts puppy popularity? Health, life span, and behavior don't matter as much as movie roles, says Stefano Ghirlanda, a Brooklyn College psychology professor who has led studies on dog popularity. A breed starring in a successful film can enjoy a boost that lasts a decade. "We were surprised the movie effect was so strong," he says. The biggest jump came for collies after the 1943 release of *Lassie Come Home* and its sequels.

Yet popularity can backfire. The film *101 Dalmatians* spiked interest in the spotted pups, but they proved too high energy for many families, says the AKC's Gina DiNardo: "They got a bad rap, and their popularity massively declined." Bulldogs, she predicts, will be the next leaders of the pack. *—Rachel Hartigan Shea*

TOP BREED





DECADE	1910s	1920s	1930s	1940s	1950s
RANK 1	Boston terrier	German shepherd	Boston terrier	Cocker spaniel	Beagle
2	Airedale terrier	Boston terrier	Cocker spaniel	Beagle	Cocker spaniel
3	Collie	Chow chow	Fox terrier	Boston terrier	Boxer
4	Beagle	Pekingese	Scottish terrier	Collie	Chihuahua
5	Bulldog	Fox terrier	Beagle	Boxer	Dachshund
6	French bulldog	Collie	Pekingese	Dachshund	German shepherd
7	English setter	Beagle	Chow chow	Pekingese	Poodle
8	Cocker spaniel	Airedale terrier	English springer spaniel	Fox terrier	Collie
9	Pekingese	Cocker spaniel	Pomeranian	English springer spaniel	Boston terrier
10	Bull terrier	Bulldog	Bulldog	Scottish terrier	Pekingese

1960s	1970s	1980s	1990s	2000s
Poodle	Poodle	Cocker spaniel	Labrador retriever	Labrador retriever
German shepherd	German shepherd	Poodle	Rottweiler	Golden retriever
Beagle	Doberman pinscher	Labrador retriever	German shepherd	German shepherd
Dachshund	Beagle	German shepherd	Golden retriever	Beagle
Chihuahua	Dachshund	Golden retriever	Cocker spaniel	Dachshund
Pekingese	Irish setter	Doberman pinscher	Poodle	Yorkshire terrier
Collie	Cocker spaniel	Beagle	Beagle	Poodle
Miniature schnauzer	Miniature schnauzer	Miniature schnauzer	Dachshund	Boxer
Cocker spaniel	Labrador retriever	Dachshund	Yorkshire terrier	Shih tzu
Basset hound	Collie	Chow chow	Pomeranian	Chihuahua

PHOTO: SETH CASTEEL. GRAPHIC: MATTHEW TWOMBLY, NGM STAFF. SOURCE: AKC

A honeybee pupa grows in its hive. In days it will emerge as an adult.

Immunity for Insects

Vaccinations aren't delivered only by doctors with syringes; they also can be passed from mother to young. This transfer was thought to be something only vertebrates could do, but scientists have discovered that some invertebrates, like honeybees, have the ability too.

Dalial Freitak and Heli Salmela of the University of Helsinki and Gro Amdam of Arizona State University found that queen bees transfer pieces of disease-causing bacteria to offspring through vitellogenin, an egg yolk protein. The protein travels from the queen's blood to a liverlike organ and then to her eggs. It's consumed by the developing bees, imparting immunity against local illnesses.

Knowing this could help scientists make a vaccine to protect bees against deadly diseases like American foulbrood, Freitak says. "It's a cornerstone in discovering new functions of the immune system." *—Lindsay N. Smith*

BUBBLES TO THE RESCUE

Walking with a filled-to-the-brim glass of water can be treacherous, but that same journey with a latte or beer is much easier. Scientists at Princeton University think they've figured out why: Foam on the surface of a liquid hinders sloshing. To test the hypothesis, the researchers created bubble layers by injecting air into a water, glycerin, and dishwashing solution. When they moved containers full of the solution in ways that would normally cause spills—quickly side to side and steadily back and forth—the bubbles damped the sloshing. Because spilling is dangerous when transporting hazardous liquids such as oil, adding foam could make those trips safer. *—LNS*

PHOTOS: ANAND VARMA, NATIONAL GEOGRAPHIC CREATIVE (TOP); REBECCA HALE, NGM STAFF

BRIGHT IDEAS CAN CHANGE THE WORLD

SEACHAR'S CLEAN-BURNING TECHNOLOGY IMPROVES LIVES IN FARMING COMMUNITIES

In the Santos region of Costa Rica, open cooking fires contributed to deforestation and made respiratory disease severe among the community's coffee bean pickers and children. *The Seattle Biochar Working Group (SeaChar)* developed the Estufa Finca (Farm Stove) to reduce harmful emissions. This innovative, clean-burning stove requires less fuel, operates on a variety of dry organic materials, and produces biochar that farmers can use as fertilizer.

SeaChar represents one of the 29 real-world projects focused on innovative energy solutions that have received grants from The Great Energy Challenge, a National Geographic initiative in partnership with Shell. When we push the way we think about energy, we help ensure a sustainable energy future.

Check out **greatenergychallenge.com** to learn more and discover new ways to change the way you think about energy in your life.

The Great Energy Challenge

NATIONAL GEOGRAPHIC

A NATIONAL GEOGRAPHIC INITIATIVE IN PARTNERSHIP WITH SHELL

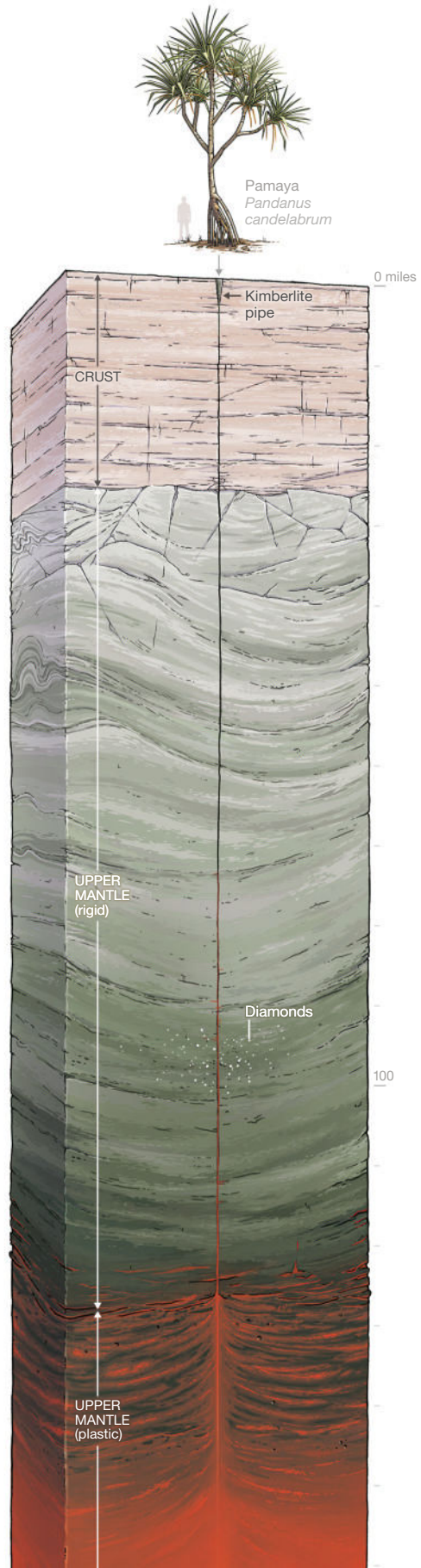
Diamond Tip-Off

In the West African nation of Liberia diamonds have been mined from rivers and streams for some 80 years. But the sources were elusive until a discovery by Stephen Haggerty, a geologist at Florida International University. While prospecting in the northwestern jungle, he came across a palmlike plant covered in thorns, likely a kind of screw pine. “It grows in thick groves that are literally impenetrable,” he says. At first he avoided those areas, but he began to suspect they were exactly where he needed to search.

Soil tests confirmed that the plants grew only above kimberlite pipes, a type of volcanic rock known to have surfaced diamonds. (To find out how, see the notes at right.) Not all such pipes contain gems, but the plants do show good spots to start digging. *—A. R. Williams*

PROMISING GEOLOGY
Large areas of Africa where the continent is old and thick are prime diamond territory. Intense heat and pressure deep underground there transformed basic carbon into dazzling gems.

MATTHEW TWOMBLY AND RYAN WILLIAMS, NGM STAFF. SOURCES: STEPHEN HAGGERTY; BRUCE KJARSGAARD

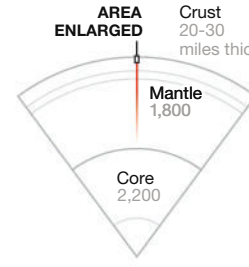


5 FERTILE GROUND
Eons of erosion broke down kimberlite to form a mineral-rich soil. A plant known locally as *pamaya* seems to thrive only there, indicating where diamonds may lie.

4 ERUPTION
Reaching the Earth’s crust, the magma blasted to the surface. It then solidified into a rock called kimberlite, which contained the diamonds picked up en route.

3 ROUTE TO THE TOP
Propelled by gases that separated out of its hot mass, the magma shot up the pipe. Its journey was quick, possibly lasting only days—or even hours—from start to finish.

2 FIELD OF GEMS
Rising in a vertical pipe, magma swept up gems lying about a hundred miles below the surface. The diamonds likely formed there as long as three billion years ago.



1 DEEP ORIGINS
Magma carried diamonds to the Earth’s surface in West Africa about 100 million years ago. The molten rock rose from the mantle, but from what depth is uncertain.

As you age, your risk of getting pneumococcal pneumonia increases. It's a serious disease that could put you in the hospital. Symptoms include coughing, fever, chest pain, and difficulty breathing. If you are 50 or older, one dose of the PREVNAR 13® vaccine can help protect you. Even if you've already been vaccinated with another pneumonia vaccine, PREVNAR 13® may help provide additional protection. Immune response may be lower if given within one year after another pneumonia vaccine. Ask your doctor or pharmacist if PREVNAR 13® is right for you.

Prevnar 13®
Pneumococcal 13-valent Conjugate Vaccine
(Diphtheria CRM_{197} Protein)

GET THIS ONE DONE.

INDICATION FOR PREVNAR 13®

- Prevnar 13® is a vaccine approved for adults 50 years of age and older for the prevention of pneumococcal pneumonia and invasive disease caused by 13 *Streptococcus pneumoniae* strains (1, 3, 4, 5, 6A, 6B, 7F, 9V, 14, 18C, 19A, 19F, and 23F)
- Prevnar 13® is not 100% effective and will only help protect against the 13 strains included in the vaccine

IMPORTANT SAFETY INFORMATION

- Prevnar 13® should not be given to anyone with a history of severe allergic reaction to any component of Prevnar 13® or any diphtheria toxoid–containing vaccine
- Adults with weakened immune systems (eg, HIV infection, leukemia) may have a reduced immune response
- In adults, immune responses to Prevnar 13® were reduced when given with injected seasonal flu vaccine
- In adults, the common side effects were pain, redness, or swelling at the injection site, limitation of arm movement, fatigue, headache, muscle pain, joint pain, decreased appetite, chills, or rash
- Ask your health care provider about the risks and benefits of Prevnar 13®. Only a health care provider can decide if Prevnar 13® is right for you

You are encouraged to report negative side effects of vaccines to the US Food and Drug Administration (FDA) and Centers for Disease Control and Prevention (CDC). Visit www.vaers.hhs.gov or call 1-800-822-7967.

Please see Important Facts for Prevnar 13® on the adjacent page.

Pfizer

IMPORTANT FACTS

Prevnar 13® (pronounced "Prev • nar 13")
Generic Name: Pneumococcal 13-valent Conjugate Vaccine (Diphtheria CRM_{197} Protein)

WHO SHOULD RECEIVE PREVNAR 13® (Pneumococcal 13-valent Conjugate Vaccine [Diphtheria CRM_{197} Protein])?

- Prevnar 13® is approved for adults 50 years and older for the prevention of pneumococcal pneumonia and invasive disease caused by the 13 vaccine strains
- Prevnar 13® is a vaccine also approved for children 6 weeks through 17 years of age for the prevention of invasive disease caused by the 13 strains of *Streptococcus pneumoniae* included in the vaccine, and for children 6 weeks through 5 years for the prevention of ear infections caused by 7 of the 13 strains
- Prevnar 13® is not 100% effective and will only help protect against the 13 strains included in the vaccine

Adults 50 years and older:

- A single dose of Prevnar 13® is recommended for adults aged 50 years of age and older

Children 6 weeks through 5 years of age:

- Prevnar 13® is recommended for children 6 weeks through 5 years of age
- Prevnar 13® is given as a 4-dose series at 2, 4, 6, and 12 to 15 months of age
- ***Transition schedule:*** Children who have received 1 or more doses of Prevnar® (Pneumococcal 7-valent Conjugate Vaccine [Diphtheria CRM_{197} Protein]) may complete the 4-dose immunization series with Prevnar 13®
- ***Catch-up schedule:*** Children 15 months through 5 years of age who are considered fully immunized with Prevnar® may receive 1 dose of Prevnar 13® to elicit immune responses to the 6 additional strains
- The immune responses from the transition or catch-up schedules might be lower for the 6 additional strains (types 1, 3, 5, 6A, 7F, and 19A) than if your child had received the full 4 doses of Prevnar 13®

Children 6 years through 17 years of age:

- In children 6 years through 17 years of age, Prevnar 13® is given as a single dose

WHO SHOULD NOT RECEIVE PREVNAR 13®?

Children or adults who have had a severe allergic reaction to any component of Prevnar 13® or any diphtheria toxoid–containing vaccine should not receive Prevnar 13®

BEFORE STARTING PREVNAR 13®

Tell your health care provider or your child's health care provider about all medical conditions, including:

- Previous allergic reactions to other vaccines
- Especially tell the health care provider if your child or you are taking medicines that can weaken the immune system, such as steroids (eg, prednisone) and cancer medicines, or are undergoing radiation therapy
- If you are pregnant or nursing, or if you plan to become pregnant

WARNING

- A temporary pause of breathing following vaccination has been observed in some infants born prematurely. Decisions about when to give Prevnar 13® to infants born prematurely should be based on consideration of the individual infant's medical status, and the potential benefits and possible risks of vaccination
- The safety and efficacy of Prevnar 13® when given to persons with a weakened immune system (such as HIV infection, damaged spleen, cancer, or kidney problems) is not known. Children or adults with a weakened immune system may have a reduced response to Prevnar 13®

WHAT ARE THE POTENTIAL SIDE EFFECTS?

- In adults, the common side effects were pain, redness, or swelling at the injection site, limitation of arm movement, fatigue, headache, muscle pain, joint pain, decreased appetite, chills, or rash
- The most commonly reported serious adverse events in children were bronchiolitis (an infection of the lungs) (0.9%), gastroenteritis (inflammation of the stomach and small intestine) (0.9%), and pneumonia (0.9%)
- In children 6 weeks through 17 years, the most common side effects were tenderness, redness, or swelling at the injection site, irritability, decreased appetite, decreased or increased sleep, and fever. Most commonly reported side effects in children 5 years through 17 years also included hives

WHAT SHOULD I KNOW ABOUT RECEIVING PREVNAR 13® WITH OTHER VACCINES?

- In adults, immune responses to Prevnar 13® were reduced when given with injected seasonal flu vaccine
- When given within 1 year following pneumococcal polysaccharide vaccine, immune response to Prevnar 13® may be lower

ADDITIONAL IMPORTANT INFORMATION

- The safety and effectiveness of Prevnar 13® when used in children less than 6 weeks of age is not known
- In a study in which children received acetaminophen prior to Prevnar 13®, immune responses to some strains in the vaccine were lower compared with responses among children who received acetaminophen after vaccination only as needed
- Ask your health care provider about the risks and benefits of Prevnar 13®. Only a health care provider can decide if Prevnar 13® is right for you or your child

NEED MORE INFORMATION?

- This is only a summary of important information. Ask your health care provider or your child's health care provider for complete product information
- Go to www.Prevnar13.com or call 1-800-666-7248

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Waco Mammoth National Monument

WACO, TEXAS

ESTABLISHED
JULY 2015

At this five-acre site—one of the most recent additions to the National Park Service system—the dig shelter offers a close-up view of mammoth bones left exactly where they were found.

Exploring a dry Texas creek bed in 1978, two young men found bones clearly too large to have come from a cow. A museum staffer at nearby Baylor University identified them as the remains of a Columbian mammoth, an extinct species that grazed here during the Ice Age. Excavations have since uncovered almost two dozen others, including a herd that died together about 65,000 years ago. The arrangement of the bones suggests that adult females surrounded their young, perhaps defending them from a rumbling flood that proved lethal.

To protect the site, its location was kept quiet until it opened to the public in 2009. The city of Waco, the university, and a fund-raising foundation developed the park and petitioned the National Park Service to adopt it. "It was as turnkey as we could ever get," says NPS curator Greg McDonald—that is, already up and running as it entered the national system. The local groups will now help run it, a new NPS approach to managing such treasures. The future is likely to bring new excavations, as old bones continue to erode from the soil. *—A. R. Williams*

PHOTO: ROD AYDELOTTE, *WACO TRIBUNE-HERALD.* NGM MAPS


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THE ALL-NEW TACOMA

Catch a Tiger by the App

With just 3,160 tigers left in the wild, keeping count is crucial. But census data are elusive, and tracking the big cats is often slow work. Though camera traps net shots like these, they can be unreliable—and poaching roils the whole process.

Enter crowdsourcing and citizen science. University of Surrey computer scientist Aaron Mason has created apps that can identify tigers by their faces and unique sets of stripes. Software scans millions of tiger photos online. When it recognizes a set of markings, that individual is added to a database that yields up-to-the-minute tallies.

Similar software is now helping conservationists analyze and monitor other species, including lions. Lions, tigers—can bears be far behind? *—Jeremy Berlin*

PHOTOS: MICHAEL NICHOLS, NATIONAL GEOGRAPHIC CREATIVE. TIGER APP: *WILDSENSE.ORG*

A Kiss Isn't Just a Kiss

Though some gestures of human affection may be timeless, kissing isn't one of them. Showing love by passionately locking lips is a fairly recent development in human evolutionary history, says a study by researchers from the Kinsey Institute at Indiana University and the University of Nevada, Las Vegas. It is hardly a universal practice—and some cultures view it as decidedly "gross."

In what its authors say is the first large study of "romantic-sexual" kissing, only 46 percent of 168 cultures surveyed had a social history that included smooching. Middle Eastern and European cultures have embraced such kissing, for example, but sub-Saharan African and Amazonian forager cultures have not.

Study author William Jankowiak suggests that kissing may be "linked to the rise of leisure" in socially stratified societies; when the elites took it up, they were mimicked by the masses. "Status trickle-down is ubiquitous in human history," he says. "And people do seem to like kissing once they discover it." *—Eve Conant*

HARD ON THE EYES

Rates of myopia have increased around the world, particularly in Asia. In China about 90 percent of 17- to 19-year-olds are nearsighted, up from an estimated 10 percent in the 1950s. Myopia is pandemic in the U.S. too, reports the National Eye Institute. Once thought to affect bookish children, nearsightedness is now believed to "arise from a lifestyle of not just too much study but of too little time outdoors," says researcher Ian Morgan. Glasses can clear up vision, but exposure to sunlight seems to be the best defense. A 2013 study in Taiwan found that spending school recess outside can prevent myopia's onset. *—Daniel Stone*

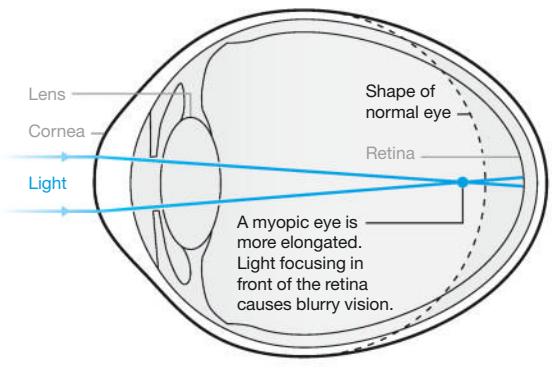

PHOTO: ELLIOTT ERWITT, MAGNUM PHOTOS. NGM ART. SOURCES: IAN MORGAN, AUSTRALIAN NATIONAL UNIVERSITY; MARY FRANCES COTCH, NATIONAL EYE INSTITUTE

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United States

He wants to help you (and your children) be farmers

CALEB HARPER *Urban farmer*

Earlier this year a ten-year-old asked Caleb Harper what causes rain. In front of them sat a "food computer," a two-by-two-by-two-foot box Harper had built to enclose a tiny farm plot. "Set the humidity to 100 percent," Harper told the boy. Inside the box it started to rain.

Teaching the next generation of farmers is only one goal for Harper, a National Geographic emerging explorer. His other, larger goal is to entirely change how people farm. The average age of farmers continues to rise worldwide. (In the U.S. it's 58.) Their land is now more likely to be bought by agribusiness companies than by younger people, who often can't afford start-up costs. In Africa more than half the population is under 35—yet younger people show little interest in the hardships of farming, say UN observers.

Harper, who leads the Open Agriculture Initiative at MIT in Cambridge, Massachusetts, says growing food in the future needs to be attractive to young people—and also scalable in cities. The food computer he pioneered is essentially a box "with a brain," he says. It resembles a terrarium or greenhouse but uses technology to optimize light, nutrients, and climate to accelerate growth. In one test a large food computer grew broccoli from seed to crown in seven weeks, about five times faster than on many conventional farms.

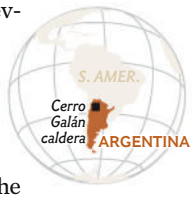
"My biggest hope is just that I'm a toolmaker, that's it," says Harper. The technology is open-source so that growers can share knowledge or propose novel uses for the system. Case in point: A sushi maker burdened by ingredient prices asked Harper if the computer could let him grow his own wasabi. *—Daniel Stone*

The most reliable way to grow food in cities in the future may be to optimize conditions inside boxes or warehouses, says Harper.

Argentina

On the road to a supervolcano

STEPHANIE GROCKE *Geologist*



Stephanie Grocke faced several hurdles on her way to the Cerro Galán caldera in northwestern Argentina, where she was investigating an ancient volcano that was the site of one of the world's largest known eruptions. She arrived in the midst of a countrywide off-road race, which meant trucks were scarce. Once she found one, she says, "the driving was pretty intense. We

PHOTO: LYNN JOHNSON. NGM MAPS

FOR SOME PATIENTS, LYRICA CAN PROVIDE SIGNIFICANT RELIEF FROM DIABETIC NERVE PAIN.*

*Individual results may vary.

Prescription LYRICA is not for everyone. Tell your doctor right away about any serious allergic reaction that causes swelling of the face, mouth, lips, gums, tongue, throat, or neck or any trouble breathing, rash, hives or blisters. LYRICA may cause suicidal thoughts or actions in a very small number of people. Patients, family members or caregivers should call the doctor right away if they notice suicidal thoughts or actions, thoughts of self harm, or any unusual changes in mood or behavior. These changes may include new or worsening depression, anxiety, restlessness, trouble sleeping, panic attacks, anger, irritability, agitation, aggression, dangerous impulses or violence, or extreme increases in activity or talking. If you have suicidal thoughts or actions, do not stop LYRICA without first talking to your doctor. LYRICA may cause swelling of your hands, legs and feet. Some of the most common side effects of LYRICA are dizziness and sleepiness. Do not drive or work with machines until you know how LYRICA affects you. Other common side effects are blurry vision, weight gain, trouble concentrating, dry mouth, and feeling "high." Also, tell your doctor right away about muscle pain along with feeling sick and feverish, or any changes in your eyesight including blurry vision or any skin sores if you have diabetes. You may have a higher chance of swelling, hives or gaining weight if you are also taking certain diabetes or high blood pressure medicines. Do not drink alcohol while taking LYRICA. You may have more dizziness and sleepiness if you take LYRICA with alcohol, narcotic pain medicines, or medicines for anxiety. If you have had a drug or alcohol problem, you may be more likely to misuse LYRICA. Tell your doctor if you are planning to father a child. Talk with your doctor before you stop taking LYRICA or any other prescription medication.

Please see Important Risk Information for LYRICA on the following page.

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.FDA.gov/medwatch or call 1-800-FDA-1088.

Ask your doctor about LYRICA and visit **LYRICA.com** or call **1-888-9-LYRICA (1-888-959-7422).**

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IMPORTANT FACTS

LYRICA® PREGABALIN © capsules (**LEER**-i-kah)

IMPORTANT SAFETY INFORMATION ABOUT LYRICA

LYRICA may cause serious, even life threatening, allergic reactions.
Stop taking LYRICA and call your doctor right away if you have any signs of a serious allergic reaction:
- Swelling of your face, mouth, lips, gums, tongue, throat or neck
- Have any trouble breathing
- Rash, hives (raised bumps) or blisters

Like other antiepileptic drugs, LYRICA may cause suicidal thoughts or actions in a very small number of people, about 1 in 500.
Call your doctor right away if you have any symptoms, especially if they are new, worse or worry you, including:
- suicidal thoughts or actions
- new or worse depression
- new or worse anxiety
- feeling agitated or restless
- panic attacks
- trouble sleeping
- new or worse irritability
- acting aggressive, being angry, or violent
- acting on dangerous impulses
- an extreme increase in activity and talking
- other unusual changes in behavior or mood

If you have suicidal thoughts or actions, do not stop LYRICA without first talking to your doctor.

LYRICA may cause swelling of your hands, legs and feet.
This swelling can be a serious problem with people with heart problems.

LYRICA may cause dizziness or sleepiness.
Do not drive a car, work with machines, or do other dangerous things until you know how LYRICA affects you. Ask your doctor when it is okay to do these things.

ABOUT LYRICA

LYRICA is a prescription medicine used in adults 18 years and older to treat:
- Pain from damaged nerves that happens with diabetes or that follows healing of shingles, or spinal cord injury
- Partial seizures when taken together with other seizure medicines
- Fibromyalgia (pain all over your body)

Who should NOT take LYRICA:
- Anyone who is allergic to anything in LYRICA

BEFORE STARTING LYRICA

Tell your doctor about all your medical conditions, including if you:
- Have had depression, mood problems or suicidal thoughts or behavior
- Have or had kidney problems or dialysis
- Have heart problems, including heart failure
- Have a bleeding problem or a low blood platelet count
- Have abused prescription medicines, street drugs or alcohol in the past
- Have ever had swelling of your face, mouth, tongue, lips, gums, neck, or throat (angioedema)
- Plan to father a child. It is not known if problems seen in animal studies can happen in humans.
- Are pregnant, plan to become pregnant or are breastfeeding. It is not known if LYRICA will harm your unborn baby. You and your doctor should decide whether you should take LYRICA or breast-feed, but you should not do both.

Tell your doctor about all your medicines. Include over-the-counter medicines, vitamins, and herbal supplements. LYRICA and other medicines may affect each other causing side effects. Especially tell your doctor if you take:

BEFORE STARTING LYRICA, continued

- Angiotensin converting enzyme (ACE) inhibitors. You may have a higher chance for swelling and hives.
- Avandia® (rosiglitazone)*, Avandamet® (rosiglitazone and metformin)* or Actos® (pioglitazone)** for diabetes. You may have a higher chance of weight gain or swelling of your hands or feet.
- Narcotic pain medicines (such as oxycodone), tranquilizers or medicines for anxiety (such as lorazepam). You may have a higher chance for dizziness and sleepiness.
- Any medicines that make you sleepy.

POSSIBLE SIDE EFFECTS OF LYRICA

LYRICA may cause serious side effects, including:
- See "Important Safety Information About LYRICA."
- Muscle problems, pain, soreness or weakness along with feeling sick and fever
- Eyesight problems including blurry vision
- Weight gain. Weight gain may affect control of diabetes and can be serious for people with heart problems.
- Feeling "high"

If you have any of these symptoms, tell your doctor right away.

The most common side effects of LYRICA are:
- Dizziness
- Blurry vision
- Weight gain
- Sleepiness
- Trouble concentrating
- Swelling of hands and feet
- Dry mouth

If you have diabetes, you should pay extra attention to your skin while taking LYRICA.

HOW TO TAKE LYRICA

Do:
- Take LYRICA exactly as your doctor tells you. Your doctor will tell you how much to take and when to take it. Take LYRICA at the same times each day.
- Take LYRICA with or without food.

Don't:
- Drive a car or use machines if you feel dizzy or sleepy while taking LYRICA.
- Drink alcohol or use other medicines that make you sleepy while taking LYRICA.
- Change the dose or stop LYRICA suddenly. If you stop taking LYRICA suddenly, you may have headaches, nausea, diarrhea, trouble sleeping, increased sweating, or you may feel anxious. If you have epilepsy, you may have seizures more often.
- Start any new medicines without first talking to your doctor.

NEED MORE INFORMATION?

- Ask your doctor or pharmacist. This is only a brief summary of important information.
- Go to **www.lyrica.com** or call **1-866-459-7422 (1-866-4LYRICA).**

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traveled over rocks and dirt the whole time." The 12,000-foot elevation gain gave her field assistant altitude sickness, and Grocke suffered from altitude-induced nightmares.

The rough trip, funded by National Geographic, was worth it. When Grocke and her colleagues finally arrived at the caldera, they found themselves in an utterly isolated landscape, one of the windiest places on Earth, with few living creatures and almost no vegetation. "I love it," says Grocke. "It's an amazing place to do volcanology fieldwork, because all the rocks are exposed."

The Cerro Galán supervolcano hasn't erupted for more than two million years, but Grocke's work is forward-looking. "We cannot predict volcanic eruptions," she says. But by analyzing rocks collected from several sites on the 22-mile-wide caldera, she can determine where the magma is. If it's close to the surface, sometime in the future this supervolcano may erupt again. *—Rachel Hartigan Shea*

Sichuan Province, China

Pandas destined to live in the wild mustn't become accustomed to humans, as photojournalist **AMI VITALE** learned while on assignment for National Geographic. At the Wolong National Nature Reserve, she watched keepers don scented panda costumes before working with the animals. While a mother panda foraged for food, keepers took the opportunity to weigh and inspect her cub. Before pandas are released from the center, they're tested to ensure they have the skills needed to survive in the wild.

Galápagos Islands, Ecuador

Galápagos tortoises: It's all in the dung

STEPHEN BLAKE *Conservation biologist*

Blake reports:

"I've just been offered a job on the Galápagos Islands," said my wildlife-vet wife. "Sounds great," I said, envisioning a life as a snorkeling and bird-watching dad. Then I met a German scientist named Martin Wikelski in a pub. He wanted to study tortoise migrations but couldn't find anyone both qualified and available. I told him I'd studied forest elephants for years in the Congo. After a couple of pints, I had a job.

Giant tortoises arrived on the Galápagos about three million years ago. Differences in their sizes on different islands inspired Charles Darwin's theory of natural selection. They dominated the archipelago until sailors started eating them; at least two species became extinct. Hunting is rare now, but threats from invasive species and development remain.

My job was to track migration. Secrets can lurk in odd places, so we set about counting seeds in piles of poo. Tortoises really are the gardeners of the Galápagos. Unfortunately they also like fruits of some invasive species.

Understanding tortoises and their habitats is important to ensure a healthy future for Galápagos tortoises. I've been fortunate to receive two grants from National Geographic, one for the tortoise seed-dispersal work, the other to delve into the secret lives of hatchlings. It's a privilege to work toward a deeper understanding of these iconic animals and advance our understanding of conservation.

PHOTO: AMI VITALE. NGM MAPS

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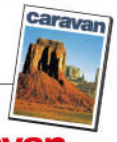

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HABITAT/RANGE
Oceans worldwide

CONSERVATION STATUS
The family Delphinidae includes Atlantic spotted dolphins (left) and 35 other species. For about half of them, scientists lack sufficient data to assess whether they're endangered.

OTHER FACTS
In Greek mythology and art, dolphins often appear as companions of Aphrodite, the goddess of love.

Social Sex Under the Sea

Having frequent, promiscuous, and arguably deviant sex has made the bonobo an infamous ape. But the dolphin, says University of Massachusetts marine biologist Richard Connor, "can out-bonobo the bonobo."

When dolphins want to procreate, the males will guard and mate repeatedly with females during an intense consortship. But throughout that time, the marine mammals still engage in "a lot of social sex," says Connor, who has studied dolphins for 30 years. By that he means "tons of male-male sex, and sex among juveniles." And he means sex for pleasure in assorted positions: belly to belly, mounting from many angles, and "goosing," a variant of the nosy way dogs check each other out. In captivity dolphins have been known to make sexual overtures toward other species swimming with them—including humans.

In light of this libido, why aren't the seas flipper to flipper full of dolphins? Because recreational sex doesn't equal reproduction. Even if males and females mate promiscuously every time the females could conceive, most female dolphins still bear just one calf every few years. With dolphins at risk from fishing, pollution, and other perils, it's a shame that these animals are so much more carnal than fruitful. *—Patricia Edmonds*

PHOTO: JIM ABERNETHY, NATIONAL GEOGRAPHIC CREATIVE

The eye of a Cuban rock iguana *(Cyclura nubila nubila)* offers a window into a fundamental truth of evolution: Form follows necessity. Four types of cone cells in this diurnal creature's retina provide excellent daytime color vision. A simpler third eye on top of the lizard's head senses light and helps regulate body temperature.

PHOTOGRAPHED AT EAST BAY VIVARIUM, BERKELEY, CALIFORNIA

The eye could be blind nature's most exquisite creation.

SEEING THE LIGHT

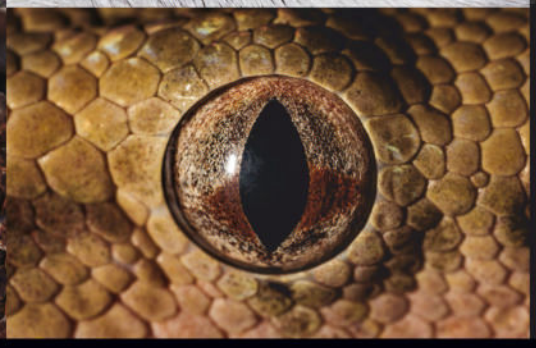


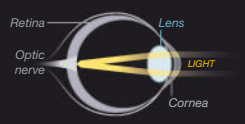












The vertebrate eyes displayed here are all variations on the same basic design, which functions much as a camera does. The cornea and lens focus incoming photons onto photoreceptor cells in the retina. These cells convert the photons into electrical signals, which are sent up the optic nerve to the brain.

Whose eyes are these? See page 57 for the answers.

PHOTOGRAPHED AT EAST BAY VIVARIUM, BERKELEY, CALIFORNIA; SAN FRANCISCO ZOO; PALO ALTO JUNIOR MUSEUM & ZOO, PALO ALTO, CALIFORNIA; SAFARI WEST, SANTA ROSA, CALIFORNIA; SENECA PARK ZOO, ROCHESTER, NEW YORK

EYE DIAGRAMS: JASON TREAT, NGM STAFF. SOURCE: DAN-ERIC NILSSON, LUND UNIVERSITY, SWEDEN

Our eyes evolved through natural selection—b
wonders. An x-ray (left) reveals a retinal chip w
skin. Fifteen hundred pixels on the chip implante
stand in for photoreceptors lost to retinitis pigm
chip stimulate the optic nerve, enabling him to s
and white (far right). Böhm volunteered for the c
again but also to help advance science.

EBERHART ZRENNER, ALPHA-IMS TRIAL RETINA IMPLANT AG, REUTLINGEN, GERM
OPHTHALMOLOGY, UNIVERSITY OF TÜBINGEN, GERMANY (ABOVE); ROBERT MACL

ut human ingenuity can perform
ired to electronics placed under the
d in Peter Böhm's left retina (above)
entosa. Signals from electrodes in the
ee the world again, at least in black
utting-edge surgery not just to see

MANY (LEFT); PHOTOGRAPHED AT ZRENNER LAB, CENTER OF
AREN, OXFORD UNIVERSITY/OXFORD EYE HOSPITAL, U.K. (INSETS)

By Ed Yong
Photographs by David Liittschwager

'IF YOU ASK PEOPLE WHAT ANIMAL EYES ARE USED FOR, THEY'LL SAY: SAME THING AS HUMAN EYES.

But that's not true. It's not true at all."

In his lab at Lund University in Sweden, Dan-Eric Nilsson is contemplating the eyes of a box jellyfish. Nilsson's eyes, of which he has two, are ice blue and forward facing. In contrast, the box jelly boasts 24 eyes, which are dark brown and grouped into four clusters called rhopalia. Nilsson shows me a model of one in his office: It looks like a golf ball that has sprouted tumors. A flexible stalk anchors it to the jellyfish.

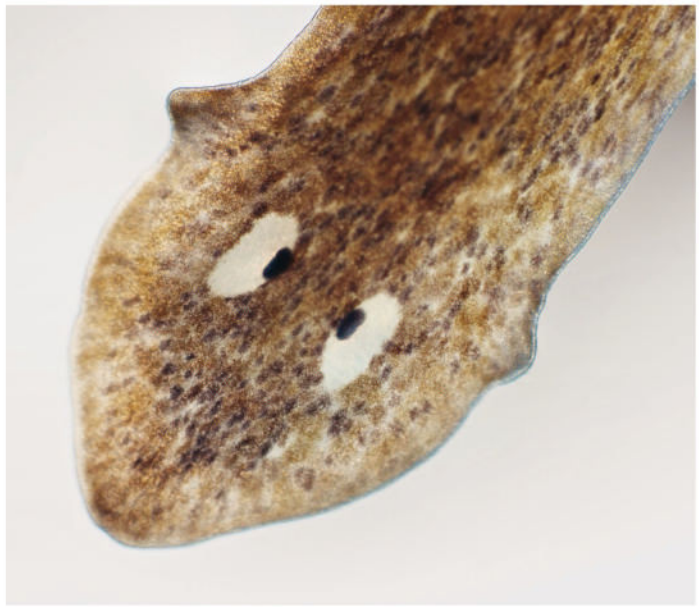
"When I first saw them, I didn't believe my own eyes," says Nilsson. "They just look weird."

Four of the six eyes in each rhopalium are simple light-detecting slits and pits. But the other two are surprisingly sophisticated; like Nilsson's eyes, they have light-focusing lenses and can see images, albeit at lower resolution.

Nilsson uses his eyes to, among other things, gather information about the diversity of animal vision. But what about the box jelly? It is among the simplest of animals, just a gelatinous, pulsating blob with four trailing bundles of stinging tentacles. It doesn't even have a proper brain—merely a ring of neurons running around its bell. What information could it possibly need?

In 2007, Nilsson and his team demonstrated that the box jelly *Tripedalia cystophora* uses its lower lensed eyes to spot approaching obstacles, like the mangrove roots that it swims among. It took them another four years to discover what the upper lensed eyes do. The first big clue was a free-floating weight at the bottom of the rhopalium that ensures that the upper eye is always looking upward, even if the jellyfish swims upside down. If this eye detects dark patches, the jellyfish senses that it's swimming beneath the mangrove canopy, where it can find the small crustaceans that it eats. If it sees only bright light, it has strayed into open water, and risks starving. With the help of its eyes, this brainless blob can find food, avoid obstacles, and survive.

The box jellyfish's eyes are part of an almost endless variation of eyes in the animal kingdom. Some see only in black and white; others perceive the full rainbow and beyond, to forms of light invisible to our eyes. Some can't even gauge the direction of incoming light; others can spot running prey miles away. The smallest animal eyes, adorning the heads of fairy wasps, are barely bigger than an amoeba; the biggest are the size of dinner plates, and belong to gigantic squid species. The squid's eye, like ours, works as a camera does, with a single lens focusing light onto a single retina, full of photoreceptors—cells that absorb photons and convert their energy into an electrical signal. By



The pair of black dots on the head of the flatworm *Dugesia dorotocephala* represent some of the simplest true eyes: unembellished pits that can sense the direction of incoming light but lack any kind of focusing lens.

contrast, a fly's compound eye divides incoming light among thousands of separate units, each with its own lens and photoreceptors. Human, fly, and squid eyes are mounted in pairs on their owners' heads. But scallops have rows of eyes along their mantles, sea stars have eyes on the tips of their arms, and the purple sea urchin's entire body acts as one big eye. There are eyes with bifocal lenses, eyes with mirrors, and eyes that look up, down, and sideways all at the same time.

At one level, such diversity is puzzling. All eyes detect light, and light behaves in a predictable manner. But it has a multitude of uses. Light reveals the time of day, the depth of water, the presence of shade. It bounces off enemies, mates, and shelter. The box jellyfish uses it to find safe pastures. You use it to survey landscapes, interpret facial expressions, and read these words. The variety of tasks that eyes perform is limited only by the fecundity of nature. They represent a collision between the constancy of physics and the messiness of biology. To understand how eyes evolved, scientists need to do more than examine their structures. They need to do what Nilsson did with the box jellyfish: understand how animals use their eyes.

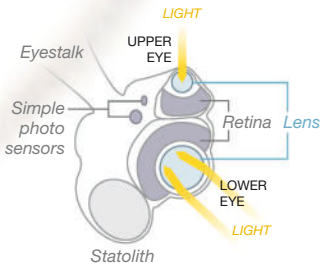
EXPLORER

Tune in Sunday, February 14, to National Geographic Channel's Explorer series episode *Eyes Wide Open.*

AROUND 540 MILLION years ago, the ancestors of most modern animal groups suddenly appeared on the scene, in an outburst of speciation known as the Cambrian explosion. Many of these pioneering creatures left fossils behind. Some are so well preserved that scientists have been able to use scanning electron microscope images to piece together their inner anatomy, eyes included, and reconstruct their owners' view of the world.

"I was amazed," says Brigitte Schoenemann from the University of Cologne. "We can even calculate how many photons they would have captured."

But these eyes were already complex, and there are no traces of their simpler precursors. The fossil record tells us nothing about how sightless animals first came to see the world. This mystery flustered Charles Darwin. "To suppose that the eye, with all its inimitable contrivances ... could have been formed by

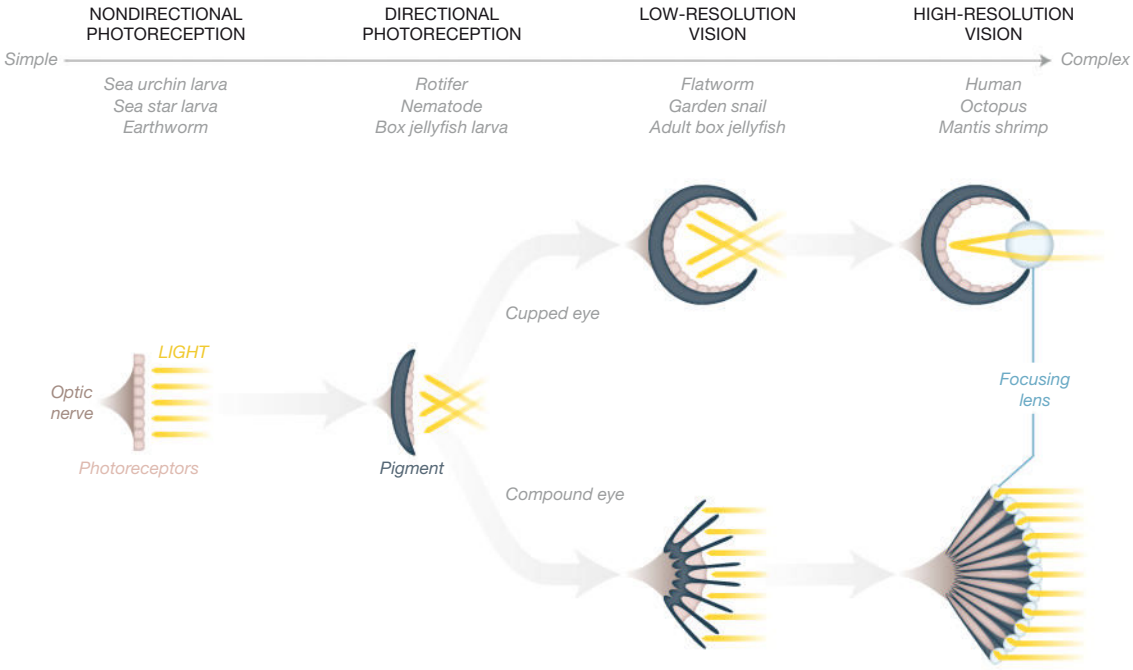


This box jellyfish *(Tripedalia cystophora)* is only about half an inch across, yet it possesses 24 eyes, housed in four rhopalia. Four of the six eyes in each rhopalium (left) are simple photo sensors, but two have light-focusing lenses. A floating crystal weight called a statolith keeps the top lensed eye always pointing upward, scanning for mangrove canopies that signal food and shelter.

PHOTOGRAPHED AT OAKLEY EVOLUTION LABORATORY, UC SANTA BARBARA
GRAPHIC SOURCE: DAN-ERIC NILSSON

THE RISE OF EYES

The diversity of eyes in the animal world illustrates how natural selection can transform simple structures that respond to light into camera-like eyes composed of multiple parts working in tandem. Dan-Eric Nilsson at Lund University in Sweden categorizes the development of eyes into four stages—an evolution that theoretically could occur in less than half a million years.



VISUAL TASKS

Organisms that sense light but not where it's coming from can regulate circadian rhythms and respond to shadows.

Animals move toward or away from light to orient their bodies and trigger alarm responses to predators.

Organisms that have developed low-resolution eyesight can detect their own motion, avoid objects, and find preferred habitats.

The most advanced eyes help animals perform complex tasks like selecting mates and recognizing predators and prey.

ADAPTATIONS

The emergence of just a few photoreceptor cells is a fundamental development that allows simple organisms to react to light.

Organisms that develop screening pigment, which partly shades their photoreceptors, can tell where light is coming from.

Cup-shaped eyes with more receptors or compound eyes with additional cups can produce crude images of objects.

Evolved sensory structures such as lenses, corneas, and irises focus light on photoreceptors, creating images with higher resolution.

GRAPHIC: JASON TREAT AND RYAN WILLIAMS, NGM STAFF
SOURCE: DAN-ERIC NILSSON

The male ostracod, or seed shrimp *(Euphilomedes morini),* has two compound eyes (brown spot, far right) to avoid predators in the water column. A female (lower left) spends most of her life buried in sand, so lacks compound eyes. Both sexes have a simple eye to tell which way is up.

COMPOSITE OF FOUR STACKED IMAGES; PHOTOGRAPHED AT OAKLEY EVOLUTION LABORATORY, UC SANTA BARBARA

natural selection, seems, I freely confess, absurd in the highest possible degree," he wrote in *Origin of Species.*

Creationists like to end the quotation there, with the great man doubting his own theory. But in the very next sentence, Darwin solves his own dilemma: "Yet reason tells me, that if numerous gradations from a perfect and complex eye to one very imperfect and simple, each grade being useful to its possessor, can be shown to exist…then the difficulty of believing that a perfect and complex eye could be formed by natural selection, though insuperable by our imagination, can hardly be considered real."

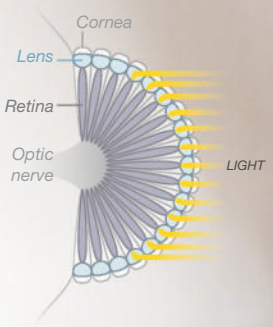
The gradations he spoke of can be shown to exist. Living animals illustrate every possible intermediate between the primitive light-sensitive patches on an earthworm and the supersharp camera eyes of eagles. Nilsson has even shown that the former can evolve into the latter in a surprisingly short amount of time.

He created a simulation that starts with a small, flat patch of pigmented light-sensitive cells. With each yearlong generation, it becomes a little thicker. It slowly curves from a sheet into a cup. It gains a crude lens, which gradually improves. Even under the most pessimistic conditions, with the eye improving by just 0.005 percent each generation, it takes just 364,000 years for the simple sheet to become a fully functioning camera-like organ. As far as evolution goes, that's a blink of an eye.

But simple eyes should not be seen as just stepping-stones along a path toward greater complexity. Those that exist today are tailored to the needs of their users. A sea star's eyes—one on the tip of each arm—can't see color, fine detail, or fast-moving objects; they would send an eagle crashing into a tree. Then again, a sea star isn't trying to spot and snag a running rabbit. It merely needs to spot coral reefs—huge, immobile chunks of landscape—so it can slowly amble home. Its eyes can do that; it has no need to evolve anything better. To stick an eagle's eye on a sea star would be an exercise in ludicrous excess.

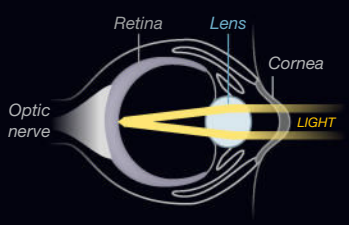
"Eyes didn't evolve from poor to perfect," Nilsson says. "They evolved from performing a few simple tasks perfectly to performing many complex tasks excellently."

A few years ago he enshrined this concept in a model that charts eye evolution in four stages, each defined not by physical structures but by the things that they allow animals to do. The first stage involves monitoring the intensity of ambient light, to gauge the time of day or the animal's



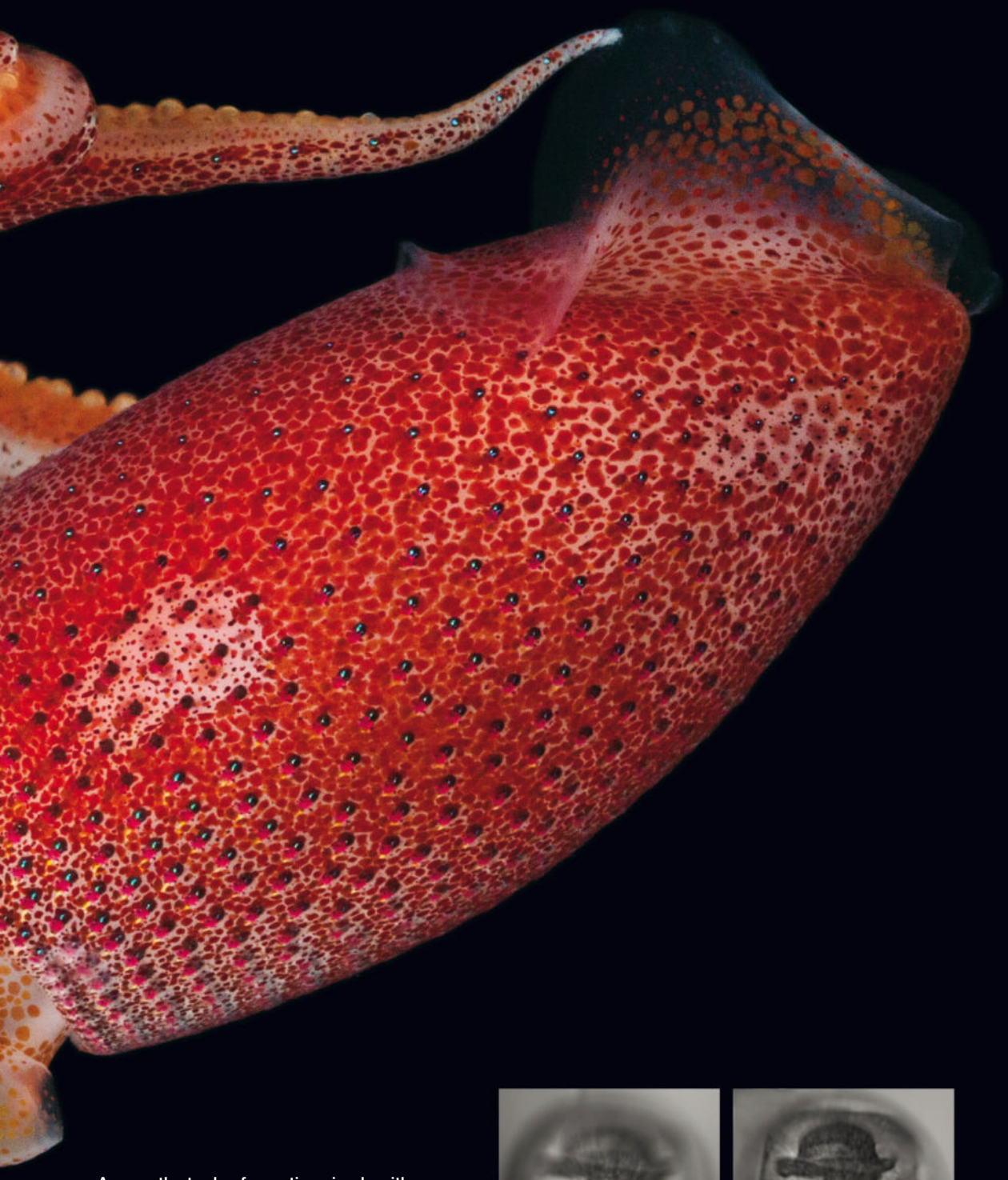
Compound eyes evolved rapidly during the Cambrian period, more than 500 million years ago. A fossilized arthropod eye from Australia with 3,000 lenses (right) would have been able to see even in dim light. "It's amazing how little has happened since then," says Dan-Eric Nilsson. A modern flesh fly (*Sarcophaga crassipalpis,* below) also sees with thousands of lenses.

COMPOSITE OF 30 STACKED IMAGES; PHOTOGRAPHED AT SCIENCE CENTRE, SOUTH AUSTRALIAN MUSEUM, ADELAIDE, AUSTRALIA (FOSSIL)
GRAPHIC SOURCE: DAN-ERIC NILSSON



Not all eyes are equal—even on the same animal. The upward-looking left eye (visible above) of the squid *Histioteuthis heteropsis* is twice the size of its right eye, the better to spot prey in light from above. The squid's smaller eye (not seen) points down into the dark below, detecting bioluminescent prey and predators.

PHOTOGRAPHED ABOARD THE *WESTERN FLYER*, MONTEREY BAY AQUARIUM RESEARCH INSTITUTE (ABOVE); ALISON SWEENEY, UNIVERSITY OF PENNSYLVANIA (INSETS)
GRAPHIC SOURCE: DAN-ERIC NILSSON



Among the tools of aquatic animals with camera-like eyes: a lens with varying tissue density, sharpening vision underwater. At right, a view of Charles Darwin as he might appear to a squid with this correction (far right) and without it.

depth in a column of water. You don't need a true eye for this; an isolated photoreceptor will do. Hydra, a small relative of jellyfish, has no eyes, but it does have photoreceptors in its body. Todd Oakley and David Plachetzki from the University of California, Santa Barbara, showed that these receptors control hydra's stinging cells, so that they fire more easily in darkness. Perhaps this allows the creature to react to the shadows of passing victims or to reserve its stings for nighttime, when its prey is more common.

In the second stage of Nilsson's model, animals can tell where light is coming from, because their photoreceptors gain a shield—usually a dark pigment—that blocks light from certain directions. A receptor like this gives its owner a one-pixel sense of the world—not enough to qualify as true vision but enough to move toward a source of light or swim away from it into a shadowy refuge. That's exactly what many marine larvae do.

In stage three, the shielded photoreceptors cluster into groups, each pointing in a slightly different direction. Now their owners can integrate information about light coming in from different directions, producing an image of their world. They can see scenes, blurry and grainy though they may be. This marks the point when light detection becomes vision proper and when bundles of photoreceptors become bona fide eyes. Animals with stage-three eyes can find suitable homes, as sea stars do, or avoid obstacles, as box jellyfish do.

Stage four is where the evolution of eyes—and their owners—really takes off. With the addition of lenses for focusing light, vision becomes sharp and detailed. "When you get to stage four, the list of tasks has no end," says Nilsson. This flexibility might have been one of the sparks that ignited the Cambrian explosion. Suddenly the rivalries between predators and prey, previously limited to sniffing, tasting, and feeling at close quarters, could play out over distance. An arms race began, and animals responded by ballooning in size, becoming more mobile, and evolving defensive shells, spines, and armor.

As they evolved, so did their eyes. All the basic visual structures that exist today were present during the Cambrian, but they have been elaborated in an extraordinary variety of ways—again for specialized tasks. The male mayfly looks like it has a huge compound eye glued on top of another smaller one, devoted to scanning the skies for silhouettes of flying females. The aptly named four-eyed fish has divided its two camera eyes in two, so one half sits above the water's surface and examines the sky while the other looks out for threats and prey below. The human eye is reasonably fast, adept at detecting contrast, and surpassed in resolution only by birds of prey—a good all-around eye for the most versatile animal of all.

Far from being an obstacle to the theory of natural selection, the evolution of the complex eye is one of its most splendid exemplars. "There is grandeur in this view of life," wrote Darwin at the end of his great work. It was his stage-four eyes that allowed him to see that splendor.

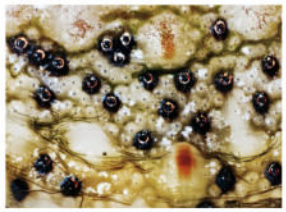
NILSSON'S MODEL SHINES fresh light on an old debate: whether eyes evolved once or many times. The legendary German evolutionary biologist Ernst Mayr claimed that eyes had between 40 and 65 independent origins, because they came in so many distinct shapes and forms. The late Walter Gehring, a Swiss developmental biologist, argued that eyes evolved just once, after he discovered that the same master gene—called *Pax6*—controls eye development in virtually every creature with eyes.

Both men were right. True stage-three eyes did indeed evolve from their simpler stage-two precursors on several occasions; box jellyfish, for instance, developed theirs independently of mollusks, vertebrates, and arthropods. But the eyes of all those organisms are elaborations of the same basic stage-one light detectors.

We know this because all eyes are constructed from the same building blocks. Nothing that sees does so without proteins called opsins—the molecular basis of all eyes. Opsins work by embracing a chromophore, a molecule that can absorb the energy of an incoming photon. The energy rapidly snaps the chromophore into a

The West Indian fuzzy chiton *(Acanthopleura granulata),* a marine mollusk, has hundreds of tiny eyes in its shell plates, each with its own lens, retina, and pigment layer. The lenses are composed not of proteins but of aragonite, a mineral the chiton forges from calcium and carbonate molecules in seawater.

BELOW: ENLARGED FROM BOXED AREA AT RIGHT (COMPOSITE OF 13 STACKED IMAGES)
PHOTOGRAPHED AT SPEISER LAB OF EVOLUTIONARY PHYSIOLOGY, UNIVERSITY OF SOUTH CAROLINA (BOTH)



different shape, forcing its opsin partner to likewise contort. This transformation sets off a series of chemical reactions that ends with an electrical signal. Think of the chromophore as a car key and the opsin molecule as the ignition switch. They turn, and the engine of sight whirs to life.

There are thousands of different opsins, but they are all related. A few years ago, Megan Porter, now at the University of Hawaii at Manoa, compared the sequences of almost 900 genes, coding for opsin proteins from across the animal kingdom, and confirmed that they all share a single ancestor. They arose once and then diversified into a massive family tree. Porter draws it as a circle, with branches radiating outward from a single point. It looks like a giant eye.

The mother of all opsins didn't arise from nothing. Evolution jury-rigged the first opsins out of proteins that functioned more as clocks than as light sensors. These ancestral proteins held on to melatonin, a hormone that controls the 24-hour body clocks of many organisms. Melatonin is destroyed by light, so its absence can signal the first rays of dawn—but only once. Any creature that senses daybreak with melatonin has to continually make more of the stuff.

In contrast, the chromophores coupled to opsins don't pose that problem. They merely change shape when they absorb light, and they can easily change back. So when melatonin-binding proteins mutated, they suddenly became reusable light sensors. Those were the first opsins. They were so efficient that evolution never came up with a better alternative; it just created variations on a theme.

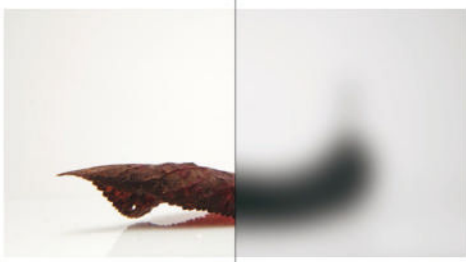
The same can't be said for other eye components. Take lenses. Almost all of them are made from proteins called crystallins, which improve their owners' vision by focusing light onto underlying photoreceptors. But unlike opsins, with their single dynasty, crystallins are unified by name only. Yours are unrelated to those of a squid or a fly. Different animal groups have independently evolved their own brand of crystallins by co-opting proteins that had very different jobs, unrelated to vision: Some broke down alcohol; others dealt with stress. But all were stable, easy to pack, and capable of bending light—perfect for making lenses.

The weirdest lenses in nature don't have crystallins at all. They belong to chitons—a group of marine mollusks that look like ovals adorned with armored plates. These plates are dotted with hundreds of small stage-three eyes, each with its own lens. The lenses are made of a mineral called aragonite, which the chitons

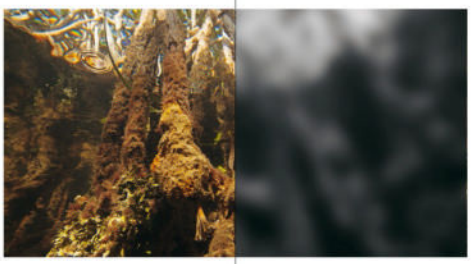
EYE OF THE BEHOLDER

It's not possible to perfectly simulate the vision of an animal, but our photographer can approximate it by combining laboratory data—such as density of photoreceptors and reactions to light—with his own tool kit.

Human vision | *Animal vision*

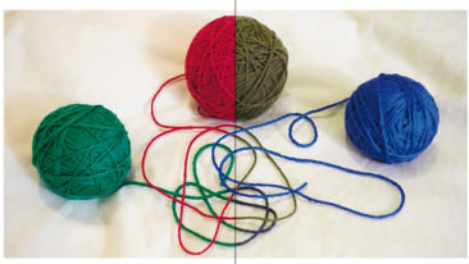


Flatworm
Dugesia dorotocephala
Flatworm eyes consist of small cups of photoreceptor cells that are able to determine which direction light is coming from. The worms need this cue to identify an appropriate habitat—one that's shaded from the sun.



Box jellyfish
Tripedalia cystophora
The box jellyfish has no brain to interpret sensory data, but it can react to simple, low-resolution images. Four lensed eyes look upward to sense mangrove shade where food is abundant. Four other lensed eyes look down through its own transparent body, to help avoid obstacles below.

Elephant hawk moth
Deilephila elpenor
The elephant hawk moth's large pupils let in abundant light, allowing it to discriminate colors even by the dim light of the stars on a moonless night. Thus guided, the nocturnal creature can find nectar in flowers whose colors are undetectable at night by human eyes.



Cat
Felis catus
The eyes of domestic cats have more low-light-sensitive rods than humans and slit pupils that can open wide in the dark, making it easy for them to hunt small animals at night. With fewer color-sensitive cones, however, cats can't differentiate between greens and reds.

Bald eagle
Haliaeetus leucocephalus
For eyes with exceptionally high resolution (2.5 times that of human eyes), look to the bald eagle. And while human retinas have one region with a high density of receptors, eagles have two, allowing them to see straight ahead and to the side simultaneously.

GRAPHIC: JASON TREAT AND RYAN WILLIAMS, NGM STAFF
SOURCE: DAN-ERIC NILSSON

The eyes of the nocturnal elephant hawk moth *(Deilephila elpenor)* excel at collecting the tiniest traces of light. Even in faint starlight, it can distinguish the colors of blossoms bearing nectar.

PHOTOGRAPHED AT WARRANT LAB, LUND VISION GROUP, LUND UNIVERSITY

assemble from calcium and carbonate atoms in seawater.

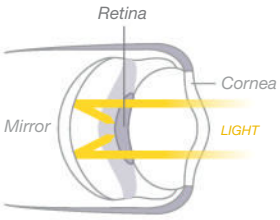
Simply put, this creature has evolved a way to sharpen its vision by looking through rocks. And when their rock lenses erode, the chitons just fabricate some new ones.

OPSINS, LENSES, AND EVERY other component of the eye are all testament to evolution's patchwork tinkering. It constantly puts existing materials to new functions, and cobbles simple structures together into complex ones. But evolution has no foresight. Once it has trundled down a particular course, it can't start from scratch again, so its works are always blighted by imperfections. Nilsson is particularly underwhelmed by compound eyes. Their structure, composed of many repeating units, sets an unforgiving ceiling on their visual resolution. If a fly wanted to see with the same resolution as a human, its eye would need to be a meter wide.

"Insects and crustaceans have become so successful despite their compound eyes, not because of them," says Nilsson. "They would have done so much better with camera-type eyes. But evolution didn't find that. Evolution isn't clever."

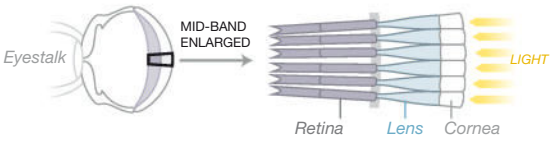
Eric Warrant, Nilsson's next-door neighbor at Lund University, takes a more lenient view. "Insect eyes have a much faster temporal resolution," he says. "Two flies will chase each other at enormous speed and see up to 300 flashes of light a second. We're lucky to see 50." A dragonfly's eye gives it almost complete wraparound vision; our eyes do not. And the elephant hawk moth, which Warrant has studied intensely, has eyes so sensitive that it can still see colors by starlight. "In some ways we're better, but in many ways, we're worse," Warrant says. "There's no eye that does it all better." Our camera eyes have their own problems. For example, our retinas are bizarrely built back to front. The photoreceptors sit behind a tangled web of neurons, which is like sticking a camera's wires in front of its lens. The bundled nerve fibers also need to pass through a hole in the photoreceptor layer to reach the brain. That's why we have a blind spot. There's no benefit to these flaws; they're just quirks of our evolutionary history.

We have evolved work-arounds. Our retinas contain long cells called Müller glia that act as optic fibers, channeling light through the morass of neurons to the underlying photoreceptors. And our brains can fill in the missing details in our blind spots. But some problems we can't avoid. Our retinas can sometimes peel away from the underlying tissue, leading to blindness; that



The mantle of the bay scallop *(Argopecten irradians)* is festooned with up to 100 brilliant blue eyes. Each contains a mirrored layer that acts as a focusing lens while doubling the chance of capturing incoming light.

GRAPHIC SOURCE: DAN-ERIC NILSSON



The mantis shrimp *Odontodactylus scyllarus* has a bewildering abundance of color receptors—twelve to our three. The eyes also move and perceive depth independently of each other, and can see infrared and ultraviolet light.

PHOTOGRAPHED AT CALDWELL LAB, DEPARTMENT OF INTEGRATIVE BIOLOGY, UC BERKELEY
GRAPHIC SOURCE: JUSTIN MARSHALL, UNIVERSITY OF QUEENSLAND, AUSTRALIA

would never happen if the neurons sat behind the photoreceptors, anchoring them in place. This more sensible design exists in the camera eyes of octopuses and squid. An octopus doesn't have a blind spot. It never gets a detached retina. We do, because evolution doesn't work to a plan. It meanders mindlessly, improvising as it goes.

Sometimes it does U-turns. Eyes are as complex as their owners need them to be, and if those needs diminish, so do the eyes. Most birds and reptiles see color with four types of cone photoreceptors, each carrying an opsin that's tuned to a different color. But mammals evolved from a nocturnal ancestor that had lost two of these cones, presumably because color vision is less important at night and because cones are most effective in bright daylight.

Most mammals are still saddled with these losses, and see the world through a limited palette. Dogs have just two cones, one tuned to blue and the other to red. But Old World primates partly reversed this loss by re-evolving a red-sensitive cone. That opened our ancestors' eyes to a previously invisible world of reds and oranges and may have helped them discriminate between ripe and unripe fruit. Marine mammals went the other way, dispensing with the blue cone when they became aquatic. Many whales lost the red cone too. They have only rod photoreceptors—excellent for seeing in the deep ocean darkness but useless for seeing color.

If the benefits of seeing dwindle to none, some animals lose their eyes altogether. The Mexican tetra excels at this. In the Pleistocene epoch, some of these small freshwater fish swam into several deep caves. Their eyes were of little use in the pitch blackness, so their descendants evolved into different populations of blind cavefish—pinkish-white creatures with skin covering where their eyes used to be. These degenerations occurred because eyes take a lot of energy to make and maintain. In particular, the neurons that carry signals from photoreceptor to brain must always be poised to fire—imagine drawing the string of a bow and keeping it taut for minutes, maybe hours.

This explains why animals don't have eyes that are better than they need and why they lose eyes so readily if they no longer need them. Squandering energy on a useless sensory system is a recipe for extinction. Eyes may be assembled from old parts, plagued by ancient bugs, and prone to breaking—but they're also exquisitely tuned to the needs of their owners. They are testament to both evolution's endless creativity and its merciless thrift.

AT THE UNIVERSITY OF MARYLAND, Baltimore County, Tom Cronin peers into an aquarium tank, and two googly compound eyes, like muffins mounted on stalks, peer back at him. "Mr. Googles," as Cronin affectionately calls him, is a gorgeous animal, bedecked in a kaleidoscopic coat of peach, white, green, and blood-red. He is a mantis shrimp—one of a group of crustaceans named for the quick-punching arms protruding beneath their heads, like those of praying mantis. Mr. Googles's arms end in formidable hammers, which unfurl with such speed and force that they can shatter seashells and aquarium glass.

"He's become a bit of a pet," says Cronin. "He's got a lot of charisma, and he's very cute."

The mantis shrimp's eyes have three separate regions that focus on the same narrow strip of space, providing depth perception without help from the other eye. They can also see ultraviolet parts of the spectrum that are invisible to us, and polarized light that vibrates in a single plane. And while we have 3 kinds of color receptors in our retinas, Cronin discovered that mantis shrimps have 12, each tuned to a different color. "It didn't make sense. None of it did," he recalls.

For years scientists assumed that with all those receptors the mantis shrimp must be the undisputed champion of color discrimination, able to detect tiny differences between hues. But Hanne Thoen, at the University of Queensland, Australia, smashed that idea in 2013. She presented mantis shrimps with optic fibers displaying different colors, and rewarded them with food if they attacked one in particular. She then adjusted the colors closer together until the animals could no longer discriminate between them. They performed appallingly:

The biggest eyes belong to the largest squid species. The eye of a giant squid *(Architeuthis dux)* at right is six and a half inches across; others up to a foot are known. They may allow the animal to make out the twinkle of glowing plankton disturbed by charging sperm whales—the squid's archnemesis.

PHOTOGRAPHED AT NATIONAL MUSEUM OF NATURAL HISTORY, SMITHSONIAN INSTITUTION

They couldn't even distinguish colors whose differences are patently obvious to our eyes.

So why all the receptors? Thoen suspects that they have everything to do with pugilistic prowess. We do a lot of visual processing in our retinas, adding and subtracting information from our cones before sending it to our brains. Perhaps the mantis shrimp instead passes the responses of all 12 of its color receptors directly up to its brain, which compares the raw data against some kind of look-up table of different colors. While the mantis shrimp is inept at discriminating between colors, such a system might make it superb at *recognizing* color, which in turn could help it make the quick decisions needed to launch its superlatively fast strikes.

But Cronin is unconvinced. Back in his lab, he dangles a pipette in a petri dish containing a smaller mantis shrimp—just a couple of inches long. It tracks the intruding object with its eyes, then lashes out. The blow is powerful enough to make an audible crack, like a finger snapping.

"That little guy spent a long time thinking before he whacked it. It's not a decision they make like that," says Cronin, snapping his own fingers. "There remains the question: What's it all for?"

It's the question that Dan-Eric Nilsson always asks as well. It's not enough to know the structure of the mantis shrimp's eyes, or the genes that are activated within them, or the neural signals that they send to the brain. Ultimately, to understand why they are the way they are, we need to know how they are used. To communicate with each other? To catch prey quickly? To better see the riot of colors in coral reefs? This is the ultimate truth of animal eyes: We can only understand their evolution when we learn to see the world through them. □

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	

Whose eyes are these?

1 Southern ground-hornbill *(Bucorvus leadbeateri);* **2** White rhinoceros *(Ceratotherium simum);* **3** Gargoyle gecko *(Rhacodactylus auriculatus);* **4** Bobcat *(Lynx rufus);* **5** African gray parrot *(Psittacus erithacus);* **6** Red-eyed tree frog *(Agalychnis callidryas);* **7** Scarlet macaw *(Ara macao);* **8** Dumpy tree frog *(Litoria caerulea);* **9** Rainbow lorikeet *(Trichoglossus haematodus haematodus);* **10** Agassiz's desert tortoise *(Gopherus agassizii);* **11** Common ostrich *(Struthio camelus);* **12** Blue-eyed black lemur *(Eulemur flavifrons);* **13** Mossy leaf-tailed gecko *(Uroplatus sikorae);* **14** Domestic dog *(Canis lupus familiaris);* **15** Western lowland gorilla *(Gorilla gorilla gorilla);* **16** Green tree python *(Morelia viridis);* **17** Human *(Homo sapiens);* **18** Panther chameleon *(Furcifer pardalis);* **19** Common boa *(Boa constrictor imperator)*

DENALI


How can six
million acres not
be enough?

A mother grizzly and her cubs cause a "bear jam" on Denali's 92-mile-long Park Road, open to private vehicles only five days each summer. Most visitors travel the route by Park Service bus (following pages), frequently spotting wildlife but rarely catching a cloudless glimpse of the park's namesake peak (preceding pages).


GMC


Denali National Park and Preserve


285.

By Tom Clynes
Photographs by Aaron Huey

Park rangers here call the high season—from June through early September, when Denali National Park and Preserve hosts the majority of its 500,000 annual visitors—the "hundred days of chaos." Indeed a midsummer morning at the park's Wilderness Access Center, located at the start of Denali's fabled 92-mile-long Park Road, can feel a bit like rush hour at Manhattan's Port Authority Bus Terminal. Loudspeakers announce bus boarding times, and visitors from many nations crowd the ticket counter.

Most of Denali's visitors are cruise ship passengers who see the park and its prolific wildlife largely through bus windows. "But if you're seeking solitude, it's not hard to find," says ranger Sarah Hayes, who helps backpackers and hikers prepare for their adventures. "We've got six million acres of mostly trailless lands where wild animals roam undisturbed. And it's accessible to anyone who hops off the bus."

As my bus rolls out, noses press against windows, hands clutch cameras, and people speaking half a dozen different tongues excitedly speculate about wildlife sightings. I ask several passengers what's on their wish list. "A moose!" "A grizzly!" "Caribou!" "A wolf!"

At the five-mile mark we spot our first animal. "Squirrel!" a kid yells, bringing the bus to laughter. After the 15-mile mark, the road turns to dirt and empties of cars. A few miles farther along the trees disappear. As the distant peaks of the Alaska Range come into view, the scale of this kingdom of nature becomes apparent. The driver slows down.

"It's been hiding for two weeks now," he says, wheeling the vehicle through a tight turn. "But there's a pretty good chance that today…" As the towering mountain comes into hazy view, a dozen voices sing out, "Denali!"

Rising 20,310 feet above sea level, North America's tallest peak is a stunning sight,

Hefting cameras and calling out in a multitude of accents, park visitors entreat bus drivers to stop when wildlife comes into view: moose, bears, caribou, sheep—and, ever more rarely, wolves.

although in warm weather its slopes are often shrouded in clouds. The mountain was a big part of the legend and lore of the Athabaskan-speaking people who gave it the name Denali, meaning Tall One. In 1896 gold prospector William Dickey renamed it Mount McKinley in honor of Ohio politician William McKinley, a staunch champion of the gold standard who one year later would become the nation's 25th president. For decades Ohio's congressional delegation successfully blocked attempts to rename the mountain. Then last summer the Obama Administration used its executive power to restore the original name.

Seeing the mountain, spotting a grizzly, or catching a glimpse of a wolf are the top three reasons people give for coming to Denali. As recently as 2010, a visitor stood a better chance of seeing a wolf in the wild than seeing the elusive Tall One, which is visible on just one in three summer days. But since 2010 the number of wolf sightings has plunged. According to a study of wildlife viewing opportunities along

the Park Road, observers recorded wolf sightings on only 6 percent of trips in 2014—down from 45 percent in 2010. Park biologists report that the number of wolves inside the park has dropped from more than 100 a decade ago to fewer than 50 last year. I came to Denali, in part, to discover why.

"I HATE TO CALL the weatherman a liar, but there's no way it was 30 below zero down there," pilot Dennis Miller says, as our ski-plane climbs away from the snowy airstrip at park headquarters. Bundled in half a dozen layers and wedged behind him in the tiny cockpit, I watch Miller shake his head. "I'll be surprised if it gets that warm all day," he says.

A few minutes later we hear the day's first radio-collared wolf in our left headphones, as an antenna on the plane's left side picks up its signal. Miller turns the aircraft and the beeps equalize, left and right. The chirping gets louder as we cross the park boundary and fly over the Stampede corridor, a notch of state, borough, and private land also known as the Wolf Townships.

"That'll be the female in the East Fork pack," Miller says. "Back in November we counted at least 15 wolves, but we found the collared male dead two weeks ago, on March 6. I've only seen a single set of tracks since then."

Following the signal, Miller descends and zigzags through a river valley where a lone wolf track heads into the trees. He throws the plane over on its left wingtip and peers down. "I'm just going to make one pass," he says, pulling the plane tighter into the turn and squinting toward the ground. "Some of the guys in these houses here, if they see me circling, they'll come out and try to find what I'm looking at and shoot it."

I've spent the previous four days flying with Miller and National Park Service biologists, whose focus turns to wolves during the snowy, light-filled days of March. Each time they've spotted a wolf inside the park that they want collared, they've called in a helicopter team to swoop down and dart it. With the animal tranquilized, biologists fit it with a collar. They also take blood and hair samples, hoping to fill some of the many gaps in what we know about the health, behavior, and genetics of one of the world's most misunderstood animals.

The research is an extension of the pioneering work of ecologist Adolph Murie, one of the first scientists to study Denali's wolves in the wild. In 1939, when Murie made the first of his many expeditions to what was then Mount McKinley National Park, wolves were considered vermin, and Park Service rangers had a history of shooting them on sight. Murie's research showed that wolves and other top predators play an essential role in healthy habitats, and he argued that we should manage parks to protect entire ecosystems rather than individual species.

Other influential scientists and thinkers would follow Murie to Denali, whose wide-open and mostly treeless mountainscapes are ideal for observing wildlife. This sprawling swath of still wild America would inspire and anchor many of the lofty ideals now considered part of the DNA of the National Park Service and incite great shifts in thinking on the role of parks and their protectors. It was here that many of the now accepted values of environmental protection and science-based decision-making gestated. The Wilderness Act has roots here, and the seeds of some of the nation's most influential environmental initiatives were planted here.

Denali has also had an outsize impact on the hundreds of thousands of nonscientists who arrive each year with dreams of a thrilling wildlife encounter and depart with a much deeper connection with the natural world. "We see it all the time," says Park Superintendent Don Striker. "They come here to snap a few pictures and get some bragging rights about being 50 feet from a grizzly. In the course of experiencing this natural drama, something clicks. They go away wanting to protect places like this."

Yet Denali has always been an uneasy paradise. The park was created in 1917 as a refuge for Dall sheep and other game animals, and its first rangers found themselves chasing poachers who supplied meat to miners and railroad builders. This tug-of-war between use and preservation would become the fundamental tension

of the national parks. Even today there are few places where it's felt as intensely, or dealt with as creatively, as it is here. The tension extends from Denali's sometimes crowded summit to its remote traplines. It reaches from the skies surrounding the mountain, which often buzz with sightseeing flights, down to the ears of solitude seekers in the trailless valleys below.

"A lot of things about this park are confusing to people," says ranger John Leonard. "It's wilderness, but then people are landing planes in some places and hunting and trapping in

THIS TUG-OF-WAR BETWEEN USE AND PRESERVATION WOULD BECOME THE FUNDAMENTAL TENSION OF THE NATIONAL PARKS.

others. That's the difference with Denali—it's not locked up. And that's what makes it so challenging to manage."

"WAS THAT YOU FLYING around the other day in a red-and-white Super Cub?" Coke Wallace asks when we meet outside his home on Stampede Road. "We thought maybe you guys were radio tracking a wolf. I almost went over to see if there was anything I could shoot."

Wallace is a trapper, hunter, guide, and self-described "extreme right-wing redneck." As he shows me his extensive collection of traps and snares and a very large wolf hide stretched over a drying rack, he gets a call on his mobile phone. Its ringtone is a wolf's howl.

"Contrary to popular opinion, I don't hate wolves," he tells me. "In fact, I think they're cool as hell. Only problem is, every five to seven years I catch the wrong wolf."

In 1999 Wallace shot a collared alpha female in the Grant Creek pack, which had been highly visible to visitors on the Park Road. In 2005 he caught the East Fork pack's alpha female in a trap set just outside the park boundary. In 2012 he dragged a horse carcass to a site where wolves were active and set traps and snares around it. When he returned a few days later, he'd trapped a pregnant female belonging to the East Fork pack. The kill, documented by a neighbor and later confirmed by Wallace, landed him in the *Los Angeles Times* and generated both death threats and a boost for his guiding business. That same year Wallace caught the only remaining breeding female in the Grant Creek pack, which often roamed just outside the park boundary. The pack consequently produced no pups and fell from 15 members to 3.

"That was the third time I ruined millions of people's Denali National Park viewing experience," Wallace quips.

Until a few years ago a wolf that strayed near Wallace's turf would have been off-limits. But Denali's most vulnerable wolf packs are at the center of some ugly politics. In 2000 Gordon Haber, the celebrated and outspoken wolf biologist who continued Adolph Murie's research, observed trappers laying snares along the park's boundary. He joined with others and persuaded the Alaska Board of Game to establish a no-kill buffer zone along the Stampede Trail and in the Nenana Canyon area. After Haber died in a plane crash in late 2009, the Park Service requested an expansion of the protected area. The board responded by eliminating it completely, making wolves vulnerable to trapping and hunting all around the park boundary.

"We increased it twice, but it was never big enough," explains Sam Cotten, commissioner of the Alaska Department of Fish and Game. "The last proposal was for another significant increase, and the feeling was that the federal government created that border and that's the line. So we went back to a harder boundary."

Although the Park Service halted its predator control decades ago, *(Continued on page 82)*

Gliding toward one of the hundreds of untouched mountainsides in Denali's high backcountry, a climber skis past sapphire pools atop upper Ruth Glacier.

Spreading through its broad valley in ever shifting braids, the McKinley River carries meltwater and silt down from the continent's highest mountain range.

Wolf Crossing

Denali National Park is one of the few places where people can see gray wolves in their natural habitat. Visitors can try to spot them from the shuttle buses along the 92-mile Park Road, but wolf numbers have dropped over the past decade. Contributing factors could be lower snowfalls, which help prey evade wolves, and trappers just outside park boundaries.

1896
Gold prospector William Dickey names the area's highest peak Mount McKinley.

1902
Geologist Alfred Brooks organizes the first mapping expedition in the mountain area.

June 7, 1913
A team led by Harry Karstens and Hudson Stuck is the first to summit Mount McKinley's south peak.

February 26, 1917
Congress creates Mount McKinley National Park. 1,591,897 acres

1923-1938
The NPS constructs the 92-mile Park Road.

1960
Bradford Washburn publishes the first topographic map of Mount McKinley.

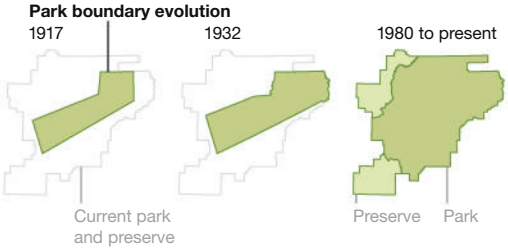
June 1972
The NPS closes Park Road to cars and institutes a shuttle-bus system to safeguard the wilderness.

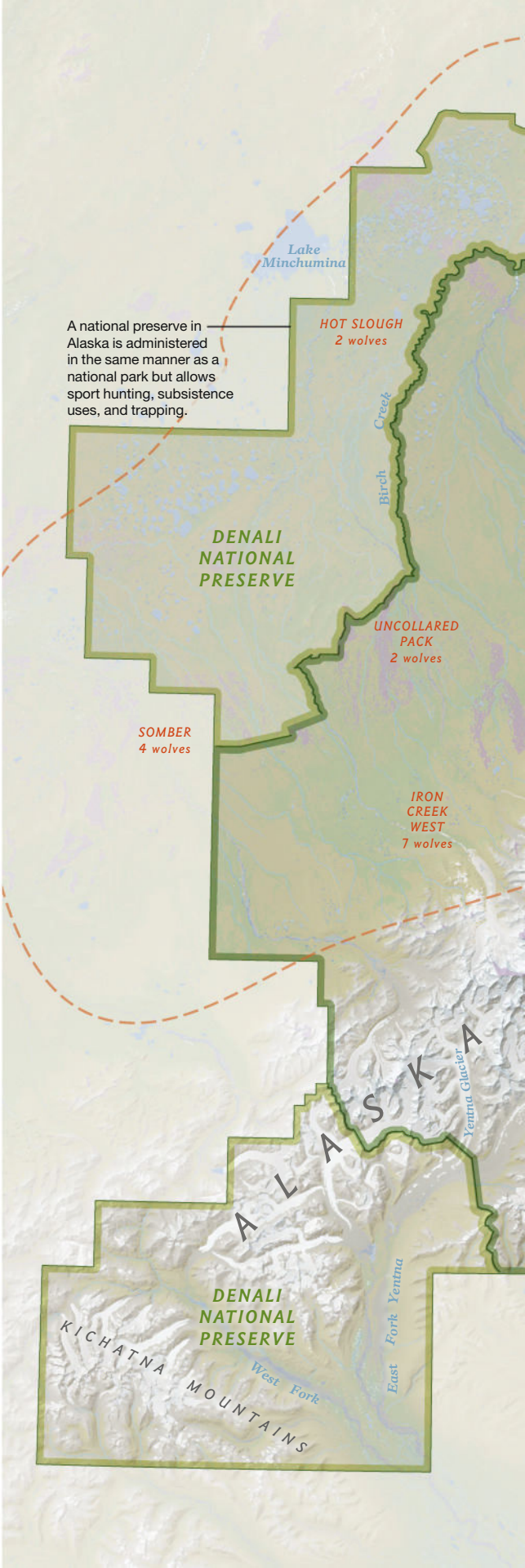
December 1, 1978
President Jimmy Carter establishes Denali National Monument. 3,890,000 acres

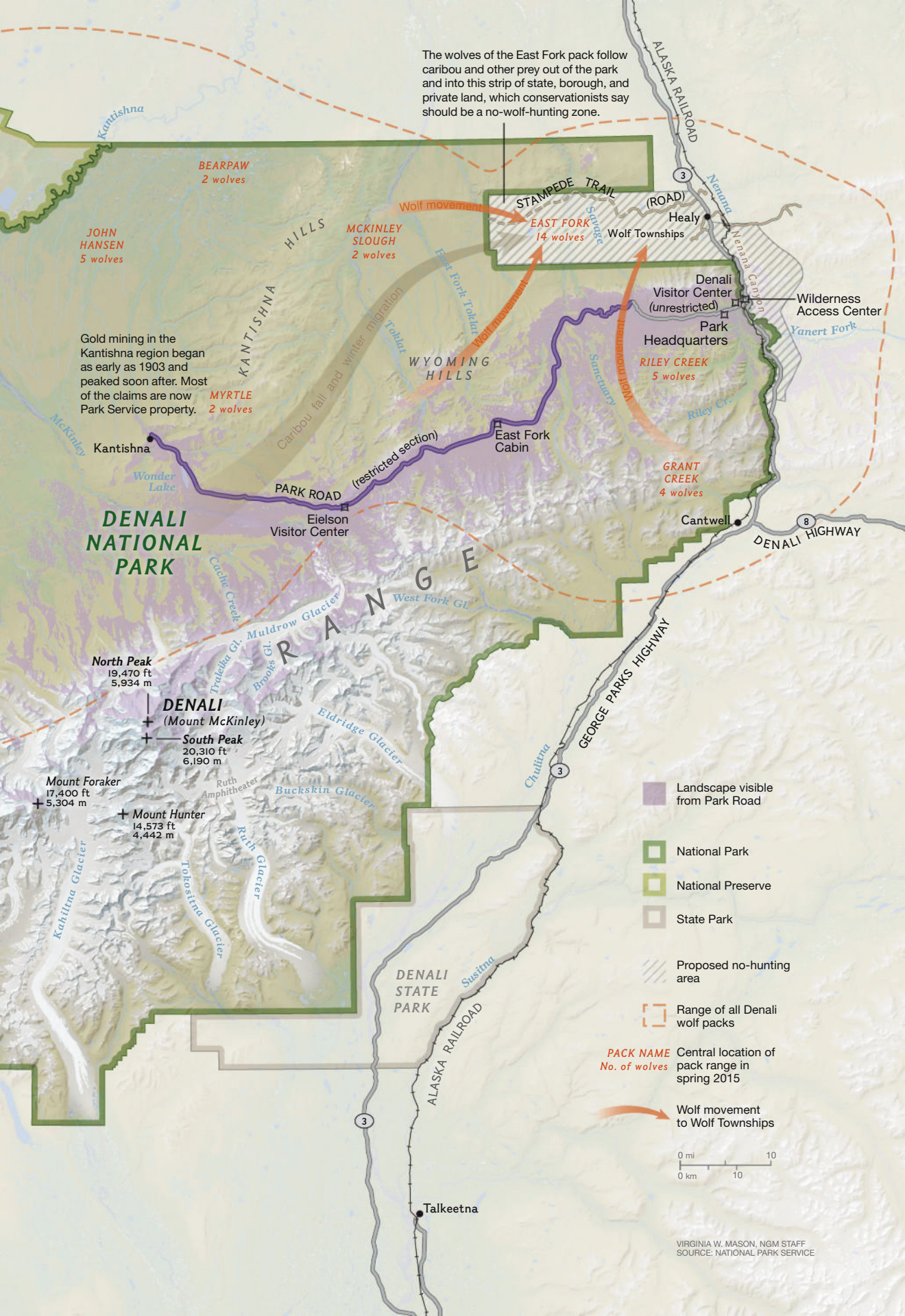
December 2, 1980
Congress enlarges Denali National Park and creates the Denali National Preserve. 6,075,030 acres

August 28, 2015
Mount McKinley is officially renamed Denali.

Park boundary evolution






The wolves of the East Fork pack follow caribou and other prey out of the park and into this strip of state, borough, and private land, which conservationists say should be a no-wolf-hunting zone.
Gold mining in the Kantishna region began as early as 1903 and peaked soon after. Most of the claims are now Park Service property.
Caribou fall and winter migration
Wolf movement
Wolf movement
Wolf movement
Kantishna
BEARPAW
2 wolves
JOHN HANSEN
5 wolves
KANTISHNA HILLS
MCKINLEY SLOUGH
2 wolves
MYRTLE
2 wolves
WYOMING HILLS
East Fork Toklat
Toklat
Sanctuary
STAMPEDE TRAIL
(ROAD)
EAST FORK
14 wolves
Savage
Wolf Townships
Healy
ALASKA RAILROAD
Nenana
Nenana Canyon
Denali Visitor Center
(unrestricted)
Wilderness Access Center
Park Headquarters
Yanert Fork
RILEY CREEK
5 wolves
Riley Cr.
GRANT CREEK
4 wolves
Kantishna
McKinley
Wonder Lake
PARK ROAD
(restricted section)
Eielson Visitor Center
East Fork Cabin
DENALI NATIONAL PARK
Cantwell
DENALI HIGHWAY
Cache Creek
RANGE
West Fork Gl.
Muldrow Glacier
Traleika Gl.
Brooks Gl.
North Peak
19,470 ft
5,934 m
DENALI
(Mount McKinley)
South Peak
20,310 ft
6,190 m
Eldridge Glacier
GEORGE PARKS HIGHWAY
Chulitna
Mount Foraker
17,400 ft
5,304 m
Ruth Amphitheater
Buckskin Glacier
Mount Hunter
14,573 ft
4,442 m
Ruth Glacier
Kahiltna Glacier
Tokositna Glacier
DENALI STATE PARK
Susitna
ALASKA RAILROAD
Talkeetna
Landscape visible from Park Road
National Park
National Preserve
State Park
Proposed no-hunting area
Range of all Denali wolf packs
PACK NAME
No. of wolves
Central location of pack range in spring 2015
Wolf movement to Wolf Townships
0 mi
10
0 km
10
VIRGINIA W. MASON, NGM STAFF
SOURCE: NATIONAL PARK SERVICE

Leading their offspring to new hunting grounds, the Iron Creek West pack's breeding pair breaks trail through fresh snow. The pair wears tracking collars fitted by biologists.

Wolves may stay near a kill site—the meal here is moose—for several days. Packs that cross park boundaries in search of prey are vulnerable to hunting and trapping.

Trapper and hunting guide Coke Wallace carries a dead wolf that he shot on his trapline just outside the park. State game officials abolished no-kill buffer zones around Denali in 2010.

the state has ramped up its wolf reduction program in some areas in an effort to boost caribou and moose populations.

"Food security for our subsistence users is a primary driver," says Cotten. "When we don't meet objectives for populations of ungulates like moose and caribou, we have to consider culls of predators."

In 2013 and 2014 state predator-control agents and authorized private hunters, shooting from aircraft, killed dozens of wolves just outside Yukon-Charley Rivers National Preserve. The cull reduced the preserve's wolf population by more than half and killed several collared wolves that had been part of a decades-long Park Service study. Although Cotten says the wolf-culling programs are based on sound science, some data undermine the premise that killing wolves leads to increased prey populations, particularly in the long term.

'IT'S GOOD POLITICS TO HATE THE PARKS AND TO OVERLOOK ALL THE GOOD THEY'VE DONE FOR THE STATE.'

Park Superintendent Don Striker

To Wallace, the wolf culls and the removal of Denali's buffer zones were long overdue. "It's the state standing up to an overreaching federal government and libtard environmentalists," he says. "I liked the park much better as McKinley National Park, when it was for sheep. Then the feds crammed that whole ANILCA thing down our throats."

In 1980 the U.S. Congress passed the Alaska National Interest Lands Conservation Act. It designated 104 million acres as national parks, forests, and preserves and protected 50 million more acres as wilderness. Mount McKinley National Park was renamed Denali National Park and Preserve, and expanded from 2 million acres to 6 million. Property rights were retained throughout the preserve, as were hunting and trapping rights in some sections.

ANILCA is widely considered among the most important conservation victories in U.S. history, but many Alaskans saw it as the culmination of years of federal overreach. Wallace was a teenager in Fairbanks when protesters there burned an effigy of President Jimmy Carter, who in 1978 elevated 56 million acres in Alaska to national monument status. In 1979 residents of towns near the park organized the Great Denali Trespass, marching into the park to shoot guns, light fires, and commit other acts of protest.

"Every other place I've been, they love their national park," says Superintendent Striker, who managed five parks in the lower 48 before coming to Denali. "But here the relationship is so poisoned by the past. People don't realize this was always federal land—it was never the state's. It's good politics to hate the parks and to overlook all the good they've done for the state, especially economically."

THE DEBATE—and everything else—seems far away when I poke my head through the tent flap at a campsite near Cache Creek in mid-March. It's the third morning of a mushing expedition and also the third morning with temperatures of minus 20 degrees Fahrenheit. I think about retreating back under the canvas, but Denali—visible most days in winter—catches my eye. Above the valley rays of sunlight splash the Tall One's summit and northeastern flanks with a dazzling orange glaze.

When I finally muster the gumption to emerge from the tent, heads turn. Thirty or so sled dogs that had been yawning in their dugout nests of snow rise and begin to yelp and howl eagerly. Dog teams are still an integral part of backcountry management here during the winter, patrolling the park's boundaries, supporting wildlife research, and hauling supplies

for cleanups and cabin restorations. And Denali's hands-on summer kennel show is the most popular demonstration program offered by the park's staff.

"The dogs connect people to history and to an experience most people will never have," says kennel manager Jennifer Raffaeli. "In the winter they're the most reliable and reasonably safe way to move around parts of the park. Unlike a snowmobile, they're always ready to start up. They also have a survival instinct, which is something no machine can ever have."

That afternoon the cold snap breaks, and we mush in a caravan of three dog teams to the ranger station at Wonder Lake. At 2 a.m. we step outside our cabins to catch a dazzling show of the aurora borealis as the dogs sleep nearby.

"A lot of Denali is untouchable to most people, but with the dogs, traveling like this, you can touch it," Raffaeli tells me as we stare in awe at the curtains of multicolored light flowing across the sky. "The sense of peace you get here in the winter is so intense it's almost beyond belief."

THREE MONTHS LATER, in late June, I experience a completely different Denali. It's 8 p.m. on the Park Road, and I'm stuck in a traffic jam. As a moose cow and two calves make their way languidly along the tree line, drivers stop in the middle of the road to point cameras.

In the 1960s Adolph Murie fought hard against plans to pave a highway into the heart of the park. He achieved a partial victory when the Park Service decided to pave only the first 15 miles. But as visitor numbers increased, the narrow road became more crowded and dangerous, and concerns grew about the impact of traffic on wildlife. In 1972 Denali became one of the first of America's national parks to set up a mass transit system to reduce the number of cars—an approach that has since been copied at other parks.

I spend a week roaming through Denali's summer backcountry, soaking up the clarifying power of wilderness. Toward the end of my trek I score a short stay in the East Fork Cabin, Murie's base while he researched the relationship between wolves and sheep. For the young ecologist, it was a dream come true. He had solitude and the chance to study animals with the simplest of tools: binoculars, a camera, notebooks, and strong legs. His focus was an extended family of wolves ranging near the cabin at the east fork of the Toklat River.

Murie's bosses in Washington, D.C., may have expected a dry research monograph. What he gave them instead was *The Wolves of Mount McKinley,* a classic work of natural history. Published in 1944, the book-length report brought the Toklat-East Fork pack to the world's attention. Murie described, for the first time, wild wolves' life cycles and relationships and the workings of an entire ecological network. Realizing that the interactions were more complicated than anyone had imagined, Murie began working to change policies that called for the eradication of predators such as wolves, mountain lions, and coyotes.

That stance made him unpopular both inside and outside the Park Service. But the more he wrote about the subjects of his research in magazines and journals, the more popular the "First Family" of American wolves became. Wildlife lovers began to travel up from the lower 48 to see them, and wolves became one of Denali's signature attractions.

On my way to the cabin the bus driver asked her passengers, "Back home, how many of you feel like every hour is rush hour?" I didn't raise


BEN MOON

A frequent *National Geographic* contributor, photographer **Aaron Huey** has trekked up Mount Everest, visited the Georgian Caucasus, and explored Indian reservations in the United States for the magazine.

While photographing in Denali, did you face any precarious situations? We skied across Ruth Glacier, which meant going over fragile snow bridges and occasionally avoiding deep ice tunnels filled with water. For safety the team was tied together with a rope for all of our travel.

Denali rangers confiscate a moose carcass from two poachers who, according to officials, crossed a marked boundary and shot the animal more than a mile inside the park.

Julie Collins feeds her dogs at the homestead she shares with her twin sister, Miki. The women have led mostly subsistence lives near the park's edge for more than 50 years.


WARNING

my hand, reluctant to admit that the never ending race against the clock has, for much of my adult life, gotten the best of me—and that for many years I've dreamed of breaking free of human-calibrated time.

I awake from a nap late that afternoon. Reflexively, I move to check my phone, then catch myself. Here there is no possibility of a text or call. The clock is no longer in command. I spend three days around the cabin—hiking, reading Murie's work, and adapting, as Emerson put it, to the "pace of nature." As I hike back toward the road, I'm not looking forward to rejoining the bustling bus scene or catching up on the news of the world.

Even the news from inside the park isn't good. I drop by park biologist Steve Arthur's office to ask about the preliminary results of the latest studies of wolf population numbers (still low) and the findings of a necropsy on a bloodied wolf carcass I saw during my winter visit. Arthur's team had dug the frozen wolf—an East Fork male—out of the snow and discovered a snare around its neck. The animal had managed to pull the snare free of its anchor, then wandered into the park and bled to death.

In May, Arthur got a call from a hunter who had legally shot a collared wolf near a bear-bait station on the Stampede Trail, just outside the park. In 2012 state game officials had expanded the controversial practice of bear baiting (which is banned in most states that allow bear hunting) to include grizzly bears. The spring baiting season overlaps wolf breeding season, making it more likely that pregnant or nursing females will be killed.

When Arthur arrived, he found another dead wolf, this one an uncollared, pregnant female. Both wolves were members of the beleaguered East Fork pack, and incoming GPS data from another wolf's collar made it clear that more pack members were still in the area, drawn by the bear bait. Arthur expressed his concern to state wildlife officials and suggested closing the wolf hunting season early in the local area. The officials agreed to close the season two weeks early on a onetime basis but rejected conservationists' calls for a permanent closure.

After five weeks in Denali—walking, skiing, flying, mushing, and bus riding through the extremes of winter and summer—I have time for one last venture into the wilderness. From a rear seat on the backpackers' bus I spot a promising route leading over a rise, then down toward the Toklat River.

I trot into the trailless landscape without a map, half hoping to get lost among the mountains and tarns. Reaching the river, I spot a hanging valley on the other side that looks much closer than it actually is. What started as a half-day hike stretches past eight hours, which is fine

Surrounded by hunting trophies, guide and pilot Ray Atkins relaxes in his cabin near the park. Guiding is big business in Alaska; Atkins charges $14,000 for an eight- to ten-day hunting trip.

with me—I've got all the daylight I need. Walking back toward the road, I flush a golden eagle from a high overlook and realize that I've been walking far more quietly than is smart in bear country. As soon as I open my mouth to speak, I top a rise and look down on a large male grizzly cooling off in a pond about 200 yards below me. When my voice reaches him, he rises on his hind legs and looks around, comically. He's a big guy, but he's not a troublemaker. He wades to shore and climbs out of the water, stopping to shake himself dry before sauntering slowly up the mountain and out of sight.

I flag down the bus a final time and step aside for a solo backpacker who's chosen this spot to disembark. He has a four-day pack on his back and a laminated map in his hand. I ask him where he's heading. He sweeps his map across the vista of mountains and valleys and rivers and sky, his eyes crinkling into a smile as he takes in a range of possibilities broad enough to be a world unto itself.

"Out there somewhere," he says. □

Evening commuters descend into the Tube station at Piccadilly Circus, in the heart of London. Excavations for a new subway line have yielded thousands of artifacts that tell the city's story from the Stone Age to today.

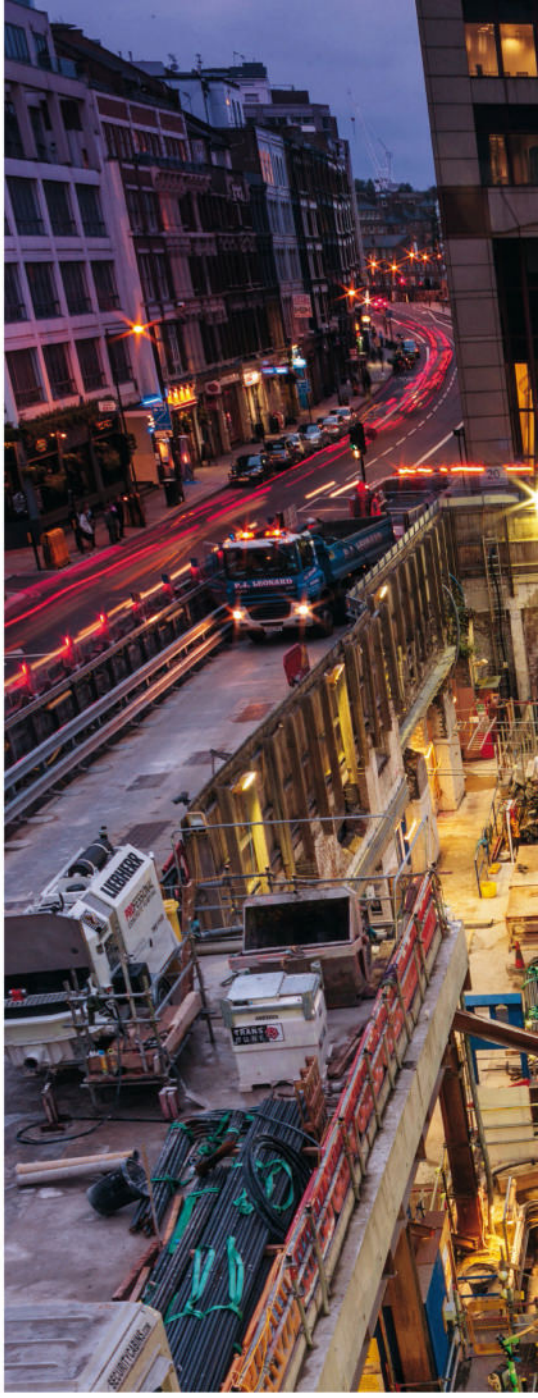
LONDON DOWN UNDER

Spurred by a building boom, archaeologists are plumbing the deep past of one of Europe's oldest capitals.

SECOND CENTURY Archaeologists unearthed these Roman-era skulls near the Liverpool Street Station. Buried around 1,900 years ago, the skulls had washed into a river channel, where smooth stones lodged in an eye socket (left).

MUSEUM OF LONDON ARCHAEOLOGY (MOLA); CROSSRAIL

By Roff Smith
Photographs by Simon Norfolk



In a brightly lit laboratory above the Museum of London Archaeology (MOLA), conservator Luisa Duarte is gently cleaning a large first-century fresco that had been brought into the museum a few days earlier from a construction site on Lime Street, in the heart of the city's financial district. Workers digging out the foundation for a new 38-story office block had come upon the ruins of an early Roman building. The museum's experts dated it to around A.D. 60, making this one of the earliest Roman frescoes yet found in London. At nearly ten feet long and more than six feet high, it's also one of the biggest and most complete.

"Whoever commissioned this was seriously rich," says Duarte, palette knife in hand, gently prying away clumps of moist earth still clinging to the fresco's surface. "A wealthy merchant, perhaps, or a banker. Somebody with taste and money and style. This bit of red, for example, appears to be cinnabar, an expensive and rarely used pigment. We come across it occasionally but only on the very finest work."

Archaeologists believe the fresco adorned a building that was demolished at the turn of the second century A.D. to make way for a grandiose new basilica and forum, the largest the Romans would ever build north of the Alps, larger than St. Paul's Cathedral is today. Entire neighborhoods were leveled, the rubble used as landfill, and the next generation's vision built on top. It was the first of many urban renewal projects over the next 1,900 years.

Peel back the pavement of a grand old city like London and you can find just about anything, from a first-century Roman fresco to a pair of medieval ice skates—even an elephant's tooth. As one of Europe's oldest capitals, London has been continuously lived in and built over by a succession of Romans, Saxons, Normans, Tudors, Georgians, Regency rakes, and Victorians, each of whom added to the pile. As a result the modern city sits atop a rich archaeological

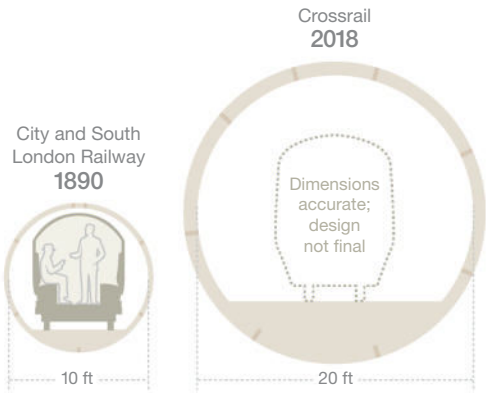
Construction work near Farringdon Station brought medieval London to light. Tests on skeletons of plague victims buried nearby showed that then, as now, London drew people from afar.

layer cake that's as much as 30 feet high.

The challenge for archaeologists is that London is also a bustling metropolis of more than eight million inhabitants, chock-full of busy streets and skyscrapers and monumental architecture. Opportunities to lift the concrete veil and poke around in the artifact-rich soil tend to be few and brief. But a perfect storm of landmark engineering projects and a building boom in the archaeological heart of London has provided an unprecedented chance to peek beneath the surface and explore the city's deep past.

The resulting haul of archaeological goodies has been almost overwhelming. They include millions of artifacts covering the vast sweep of

London's first underground railway tunnels were only ten feet wide. Later, advances in technology led to safer, wider tunnels, able to hold larger trains and thus ferry more Londoners to and fro.



human history along the River Thames—from the early Mesolithic, some 11,000 years ago, to the late Victorian, at the end of the 19th century. The discoveries also include the bones of thousands of rank-and-file Londoners who died and were buried in graveyards that were built over and forgotten centuries ago.

"These excavations have provided us with fascinating snapshots into the lives of Londoners through the ages," says Don Walker, a human osteologist, or bone specialist, for MOLA. "It makes you realize that we all are just small, passing players in a very long-running story."

One of the earliest chapters of that story came to light after 2010 at the three-acre building site for Bloomberg London, the soon-to-open European headquarters of the Bloomberg financial empire. Located in the ancient ward of Cordwainer, where leather workers had plied their trade since Roman times, a 40-foot-deep excavation pit turned out to be one of the most significant early Roman sites ever found in London.

As the soil was removed, entire street scenes were revealed, complete with timber-framed shops, homes, fences, and yards. Dating from the early 60s A.D. onward, the site was in such an astonishing state of preservation that archaeologists dubbed it the "Pompeii of the north." More than 14,000 artifacts were found over the course of the excavation, including coins, amulets, pewter plates, ceramic lamps, 250 leather boots and sandals, and more than 900 boxes of pottery.

"This was the richest haul of small finds ever to come out of a single excavation in the city," says archaeologist Sadie Watson, who supervised the dig for MOLA. "It's giving us an unprecedented glimpse into everyday life in Roman London."

In the trove were nearly 400 rare wooden writing tablets, some of which still displayed legible letters, legal agreements, and financial documents. (Another site yielded shopping lists, party invitations, and a contract for the sale of a slave girl.) The extraordinary preservation is owed to a forgotten little stream called the Walbrook, which flowed through the heart of Roman Londinium on its way to the Thames. Its marshy banks and waterlogged soils preserved almost anything that fell into them.

"Good old English damp," Watson says, laughing. "Thanks to the Thames and its tributaries, London has one of the best environments for preserving artifacts that anyone could hope to have. Leather, wood, and metal objects that would rot or rust away anyplace else come out of the ground here in amazingly good condition."

BY FAR THE BIGGEST BOON to London archaeology has been the $23 billion Crossrail project, the new east-west underground commuter rail link that is both Europe's largest engineering project and its biggest archaeological dig. Since work began in 2009, Crossrail's 26 miles of tunnels and more than 40 construction sites have turned up thousands of artifacts and fossils spanning the past 70,000 years.

The largest and most spectacular excavation was launched this past spring in front of the busy Liverpool Street Station. Plans to build an underground ticketing hall meant cutting through the old Bedlam burial ground, the city's first municipal cemetery. The job entailed exhuming the skeletons of more than 3,300 Londoners; most died in the 16th and 17th centuries, when the city's streets were often stalked by plague.

DAISY CHUNG. SOURCES: CROSSRAIL; LONDON TRANSPORT MUSEUM

With churchyards rapidly filling up with plague victims, city officials decided to establish a public cemetery to accommodate the overflow. The governors of the Bethlem Royal Hospital—popularly known as Bedlam, Europe's first insane asylum—sold them one acre of land in 1569. Because it was not affiliated with any church, Bedlam became the resting place of choice for radicals, nonconformists, migrants, and misfits, as well as the working poor. By the time the cemetery finally closed, sometime around 1738, it was filled to capacity many times over, with an estimated 30,000 dead buried there.

"The Bedlam burial ground is the most diverse graveyard in the city," says Jay Carver, Crossrail's chief archaeologist, whose team spent months researching the site before starting the excavation. "The whole spectrum of society is represented here, from madmen and criminals to the wife of a former Lord Mayor of London."

Carver and I are standing on a viewing platform overlooking the excavation. In the pit below, a team of 30 archaeologists in orange overalls and blue hard hats are brushing soil from the brows of skulls. Many of the skeletons being exhumed are believed to have perished in the great plague outbreak of 1665, which killed 75,000 to 100,000 Londoners out of a total population of around 450,000.

Scientists plan to run tests on some of the remains in hopes of learning about the evolution of the plague bacterium that killed so many. "One of the great mysteries is why the plague never returned to London after 1665," Carver says. "Up until that time it was a fairly regular visitor to the city, but never afterwards. Why? What changed? We're hoping this can provide some answers."

Identifying the remains of individual people in the old Bedlam cemetery is next to impossible. Although some of the coffins had initials on them, tombstones were broken up and reused in walls and buildings when the area was redeveloped. But one set of bones that might be identified is that of Robert Lockyer, a populist radical who was executed by firing squad in 1649. He was buried at Bedlam with the biggest funeral the old graveyard ever saw, attended by more than 4,000 mourners. Carver is keeping a special eye out for him. "If we come across any skeletons with musket-ball holes, we'll have a pretty good idea whose it is."

The manner of Lockyer's passing would give his skeleton a certain historical cachet, but the bones of others may tell a more interesting tale. "Skeletons normally tell us much more about how people lived than how they died," says Don Walker, the osteologist.

Isotope and bone analysis from a collection of 14th- and 15th-century skeletons unearthed during an excavation at Charterhouse Square paint a harrowing picture of life in medieval London. Many showed signs of malnutrition, and one in six suffered from rickets. Severe dental problems and tooth abscesses were also common, as was a high rate of back injuries and muscle strains from heavy labor. People from the latter period, in the 1400s, had disturbingly high rates of upper body injuries, possibly consistent with violent altercations that resulted from a breakdown in law and order in the wake of the plague.

And yet London still seemed to be a powerful draw for country folk seeking a better life. Isotope analysis reveals that nearly half of the skeletons tested were individuals who had grown up outside the city, some having migrated from as far away as northern Scotland. "It would seem that 14th-century London was already drawing people from all around Britain, just as it does today," Walker says.

IT'S EIGHT O'CLOCK on a damp weekday morning, and the sidewalk in front of the Cannon Street Station is bustling with commuters. Few if any notice the iron grille set into the foundation of a former bank building across the street, let alone peek between the bars to see the chunk of limestone that resides there, tucked away for safekeeping. It is the London Stone.

What its original purpose was no one can say, although legend has it that the city will fall if the stone is ever removed or destroyed. It's mentioned in property deeds dating back to 1108 and was considered an *(Continued on page 108)*

SECOND CENTURY Digging at a new hotel site in 2013, archaeologists uncovered one of the best preserved sculptures from Roman Britain. It depicts a serpent writhing in the clutches of an eagle and may have adorned the mausoleum of an official.

MOLA; ENDURANCE LAND AND ABERDEEN ASSET MANAGEMENT

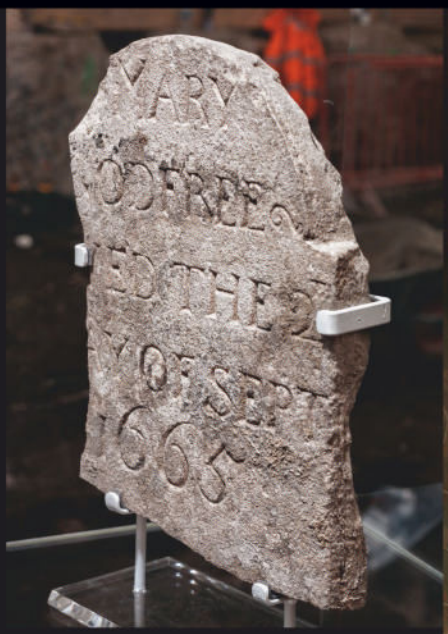
14TH CENTURY Half of London's population died during the Black Death pandemic of 1348-1350. Victims included these individuals, whose skeletons were uncovered near Charterhouse Square.

MOLA; CROSSRAIL

CASHBOX AND CANNONBALL—ROLLED FOR THUNDER SOUND EFFECTS—FROM THE EXCAVATION OF THE SHAKESPEAREAN-ERA ROSE THEATRE (MUSEUM OF LONDON)

13TH-CENTURY PERFUME BOTTLE FROM THE MIDDLE EAST (MOLA)

SOUVENIR PLATE FROM QUEEN VICTORIA'S CORONATION IN 1838 (MOLA)



HEADSTONE OF A 1665 PLAGUE VICTIM FROM BEDLAM BURIAL GROUND (MOLA; CROSSRAIL)

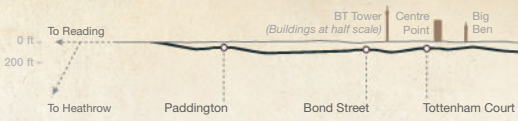
NEOLITHIC HAND AX UNEARTHED AT THE SITE OF THE LONDON OLYMPICS (MUSEUM OF LONDON)

SUNKEN CITY

The new Crossrail route runs for 73 miles (26 miles underground) through a metropolis that has been growing for centuries.

UNEARTHING LONDON

Crossrail project teams are contributing to a rich archaeological record, exhuming historical treasures buried under the city.

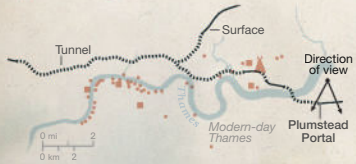


A BRONZE AGE (2000–600 B.C.)

Plumstead Portal Area

Nomads built tracks from tree trunks across these marshes to make travel and hunting easier. Crossrail teams found a stone hammer and wooden stakes with pointed ends.

Settlement · Wooden structure · Other artifacts



B ROMAN PERIOD (A.D. 43–410)

Liverpool Street

Roman rule marked a period of growth for the settlement of Londinium. Remains of a large road as well as skulls from nearby Roman cemeteries were found at this construction site.

Second-century population **35,000**

C MEDIEVAL LONDON (1066–1485)

Farringdon Station

The discovery of 25 skeletons provides evidence of London's second emergency burial ground for victims of the Black Death (1348-1350). Half the city's population died.

1300 population **80,000**

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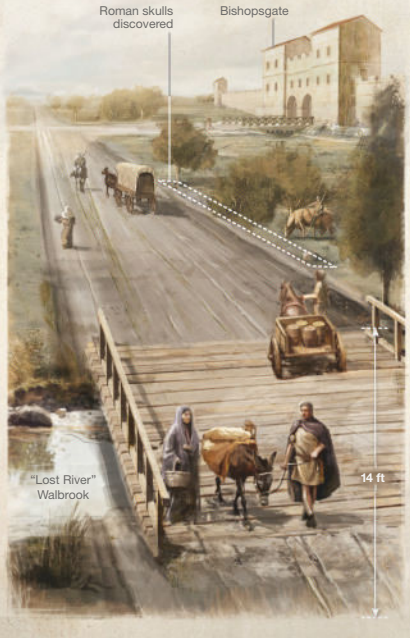
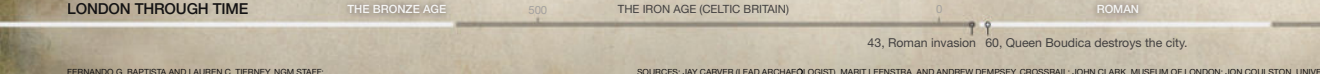
London has rebuilt itself many times, raising the ground level.

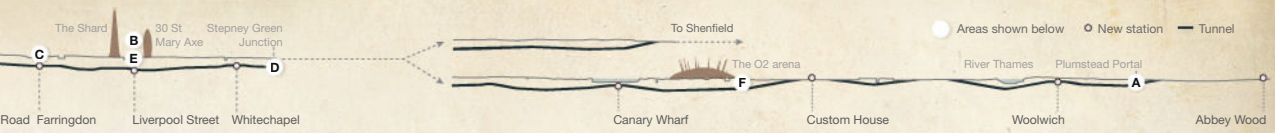


LONDON THROUGH TIME



FERNANDO G. BAPTISTA AND LAUREN C. TIERNEY, NGM STAFF; VICTORIA SGARRO, DAISY CHUNG

SOURCES: JAY CARVER (LEAD ARCHAEOLOGIST), MARIT LEENSTRA, AND ANDREW DEMPSEY, CROSSRAIL; JOHN CLARK, MUSEUM OF LONDON; JON COULSTON, UNIVE
THE LONDON ENCYCLOPAEDIA; ORDNANCE SURVEY; *LONDON: THE ILLUSTRATED HISTORY*; *LONDON: THE INFORMATION CAPITAL*



OR (1485–1603)

ney Green Junction

aeologists found the remains of a manor known as King s Court, which boasted its own moat. The residence later ered Protestant nonconformists and Puritans.

population **125,000**

E MID-17TH CENTURY

Liverpool Street

Thousands of skeletons were unearthed here, the first public burial site outside London's city walls dedicated to overflow from city parishes, including casualties of the 1665 great plague.

1660 population **450,000**

F VICTORIAN ENGINEERING (MID-19TH CENTURY)

Shipyard

Remains of the Thames Ironworks and Shipbuilding Company, creator of some of the world's most famous warships, bear witness to Britain's industrial past.

1831 population **1,600,000**

500 ANGLO-SAXON 1000 MEDIEVAL 1500 TUDOR STUART GEORGIAN VICTORIAN 20TH CENTURY

604, St. Paul's Cathedral founded

1066, Norman invasion

1215, Magna Carta

1666, The Great Fire

1863, World's first underground railway

RSITY OF ST. ANDREWS; TRANSPORT FOR LONDON;

Peel back the pavement of a grand old city like London and you can find just about anything, from a first-century Roman fresco to a pair of medieval ice skates—even an elephant's tooth.

old, old landmark even then. Sixteenth-century antiquarian William Camden believed it was a Roman milliarium, the ground-zero milepost from which all the distances in Roman Britain were measured.

It gets a mention in the plays of William Shakespeare and the poems of William Blake. For centuries it sat in the middle of the street, a folkloric landmark, until 1742, when it was finally deemed a traffic hazard and shifted to the north side of the street, out of the way. There it has remained ever since, at first beside the entrance to St. Swithins Church and later, after the church was destroyed during the blitz, set into a recess in the wall of the new building.

"What the London Stone is supposed to be is a bit of a mystery," says Jane Sidell, inspector of ancient monuments for Historic England, the national body that champions preservation of landmarks. "But it plays a role in the history of archaeology in London." When Sir Christopher Wren rebuilt St. Swithins Church, for instance, after the Great Fire in 1666, he made a point of erecting a cupola around the nearby London Stone in order to protect it. This is the first known example of somebody going out of their way to protect an archaeology site in situ.

Wren took rather less care about the substantial Roman ruins he uncovered while digging the foundations for St. Paul's Cathedral. Fortunately for posterity another man did, a local antiquarian named John Conyers, who followed Wren's workmen around, taking notes, bagging artifacts, and making detailed drawings in what modern historians regard as one of the world's first formal archaeological investigations.

Conyers also recorded the excavation of a mammoth a few years later, near Kings Cross, and was the first to argue, successfully, that the flint hand ax found nearby was of human origin. "Previously these sorts of things were said to be 'faerie thunderbolts,'" Sidell points out.

But it wasn't until the 1840s, when Victorian engineers began tunneling under the city to build an extensive sewer system, that the newfound science of archaeology found its feet. A pharmacist, coin collector, and amateur antiquarian named Charles Roach Smith cast aside social convention, put on old clothes, and dropped down into the tunnels to follow the workmen. Like Conyers, he observed their digging, took notes, made drawings, and salvaged whatever artifacts he could. "It was the beginning of construction site archaeology as we know it," says Crossrail's Jay Carver.

Roach Smith became the nation's foremost authority on Roman British antiquities, and his book *Illustrations of Roman London* was the definitive work on the subject for 50 years. His personal collection of artifacts later formed the nucleus of the Museum of London's own Roman British collection. By a curious quirk of fate, the site of Roach Smith's former home at 5 Liverpool Street is occupied today by the office block where Crossrail's archaeology team is based, a coincidence not lost on its chief archaeologist. "Roach Smith occupies a special place in our thinking," he says. "Although he was working 150 years ago, his observations and notes have been useful in alerting us to the potential of various sites around the city."

NOT ALL OF LONDON'S archaeology is underground. Imposing segments of the original

second-century Roman wall that once encircled the city can still be seen in places such as Tower Hill or St. Alphage Garden, or beside the Museum of London itself, where a stretch of Roman wall was exposed by the German Luftwaffe during a night bombing raid in 1940. Park your car in an underground garage nearby and you can nose your bumper up to one of the city's original gates. Get your hair cut at the barbershop on the corner of Gracechurch Street and Leadenhall Market, and in the basement downstairs you can see an arch support for the second-century Roman basilica.

"But London's biggest and most visible archaeology site is the Thames, when the tide is out," says Nathalie Cohen, leader of the Thames Discovery Programme at the Museum of London Archaeology.

It's just after sunrise on a clear winter's morning, with the dome of St. Paul's Cathedral shimmering in the low-angled sunshine. We're on the Thames embankment just below the cathedral, making our way down a set of algae-covered stone steps to the freshly exposed foreshore. It's a jumble of water-smoothed cobblestones, roofing tiles, animal bones, crockery, broken bits of clay tobacco pipes, rusty iron, and chunks of thick colored glass that have been rounded and frosted by the relentless action of the tides.

"Almost everything you see here is archaeology," says Cohen, who points out a Roman-era roofing tile here, a piece of blue-patterned Victorian porcelain there, as we scramble over the uneven ground. "With every tide this gets jumbled up again. It's never the same twice. You never know what you'll find."

Much of the foreshore is accessible to the public and popular with amateur archaeologists and metal detector enthusiasts—hobbyists whose talents and energy Cohen and her colleagues have enlisted to record, monitor, and safeguard protected sites along the foreshore. One of these is Queenhithe, an indentation in the riverbank just below the Millennium Bridge. First recorded in Anglo-Saxon documents of the late ninth century, it was used by ships well into the 20th century.

It's also the haunting burial site of two Saxon-era women, one of whom appeared to have been executed by a blow to the head from a sword or ax and buried here between A.D. 640 and 780. "This would have been a creepy spot in those times," Cohen says. "By then the Romans had been gone for more than 200 years, and the ruins of the city would have been overgrown and falling down and very lonely."

BACK AT LIVERPOOL STREET archaeologists have sifted their way down to the early Roman level of London's great mound of history. Here, outside the old city walls, in the dark mud that marks a former course of the Walbrook River, they make an intriguing discovery: an old cooking pot with the lid still on it, crammed with cremated human remains. Somebody had buried it along the riverbank nearly 2,000 years ago. Another 40 human skulls, possibly those of executed criminals or rebels, were found nearby.

"We've known for a long time that people had found Roman-era skulls along the Walbrook, but we'd always assumed they had been eroded out of a Roman cemetery and washed downstream," Carver says. But the latest evidence suggests something different. "Looks like we're going to have to go back over the finds that have been made along here over the past two centuries and rethink what was going on."

Looking down at the dark line of earth that marked where the vanished river once flowed, with the murmur of London traffic in my ears, I found myself thinking of the opening scene in *Heart of Darkness.* Joseph Conrad's narrator, the garrulous seaman Marlow, reminds his listeners as they sit watching the sun set over London, "And this also... has been one of the dark places of the earth." □

CHERYL SMITH

Based a few hours by train from London, writer **Roff Smith** has pursued stories for *National Geographic* on every continent. A recent feature, "Before Stonehenge," was the August 2014 cover story.

The Changing Face *of* Saudi Women

In a deeply conservative culture, women are carefully redefining the boundaries of respectable public life. Modesty around strangers is obligatory, but some women now feel comfortable using social media like Instagram to celebrate their identities.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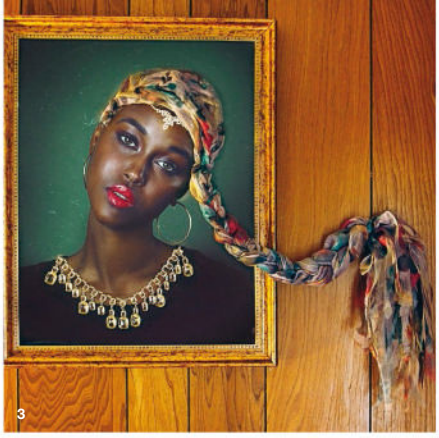
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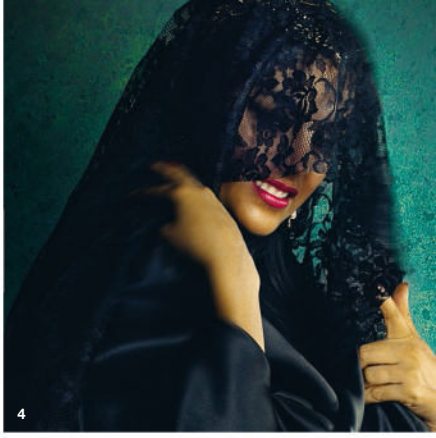
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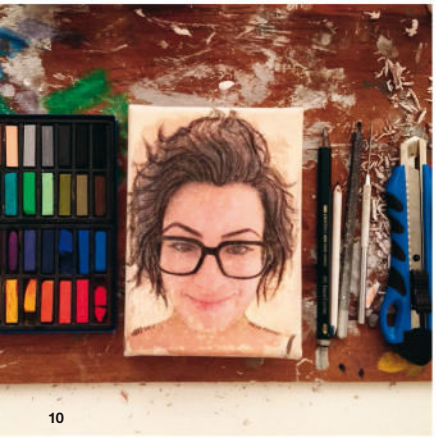
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POWER BRUNCH, SAUDI VERSION Aljazi Alrakan (standing), a dentist and self-described lifestyle blogger, joins friends in a fashionable Riyadh restaurant. Medicine and teaching were careers open to Saudi women early on;

both suited a single-sex clientele. With more women than men now in universities, “there are new careers,” Alrakan says. “I look at girls in their early 20s, and I think, They carry themselves more confidently.”

GLAMOUR FINDS ITS OWN DISPLAY In the comfort of no-men-allowed settings, like this fashion show put on by an Italian stylist in a Riyadh store, Saudi women of means explore different styles. Models like this one are often

foreign, as that role is still seen as risqué. A woman's new party dress and eye makeup might be seen only by her husband and female friends; for those who can afford these things, they're enticing nonetheless.

By Cynthia Gorney
Photographs by Lynsey Addario

SEPARATION IS EVERYWHERE, EVEN IN LINE

Food outlets, like this café in Riyadh, must follow unique Saudi laws: All lines, counters, and eating areas are divided to keep unrelated men and women apart, although customers sometimes ignore the signs. Saudi authorities insist, to an extent unmatched in any other Muslim country, that Islam demands this separation in public and that these rules keep society orderly, honor tradition, and show respect for God.

Inside her family's sitting room, where she had plumped onto a sofa to pour us Arabic coffee, Noof Hassan was testing out the word "headhunted." She had never learned this in her English classes at school, and when she heard me say it, she made me repeat it because she liked it so much. "Yes!" she said. "I was headhunted. I'd had many offers before. But this time even my boss said, 'We don't want you to go—but this is a good offer.'"

Noof is 32 and has thick brown hair, caramel skin, and merry, almond-shaped eyes. The apartment she shares with her husband, Sami, and their two small sons takes up one floor of a three-story building in a crowded neighborhood of Riyadh, the capital of Saudi Arabia. Two years ago, the first time I met her, she was a manager in a food-processing factory, overseeing a dozen workers in an experimental all-female wing that was part of a nationwide campaign to draw Saudi women into paying jobs. Now, in the lighting assembly plant that had just poached her away, Noof was in charge of ten times that many. Her salary had shot up too.

"They have given me a nickname there," she said. The women Noof supervises work in an area off-limits to men, but this company's managerial offices are "mixed," as the Saudis say: men and women, unrelated by blood or marriage, in close proximity every day. Addressing each other with more than formal courtesies. Attending meetings at the same conference table. Maybe poring side by side over the same document. Saudi Arabia is the most profoundly gender-segregated nation on Earth, and amid the fraught, fragile, extraordinary changes under way in the daily lives of the kingdom's women—multiple generations, pushed by new labor policies and the encouragements of the late King Abdullah bin Abdulaziz, are now debating what it means to be both truly modern and truly Saudi—this matter of mixing remains very controversial indeed. There are women here who won't even consider a job that requires it.

There are women who *might* consider such a job but are overruled by their parents, or their husbands, or worried relatives saying, no, not you; other Muslim countries may permit such a thing, but in Saudi Arabia this is not what decent women do. There are women at the opposite end of the spectrum too, quite at ease with male colleagues—in the past decade, government scholarship programs have sent tens of thousands of Saudi women to study abroad, and they're coming home, many impatient to push the pace of change.

Somewhere along that complicated spectrum, improvising to suit her own ideas about dignity, Noof has established her personal requirements inside the company offices: no physical contact with men, please, no matter how incidental. "The lady who is training me understands," Noof said. "I told her, 'This is not because I have a baby and am worried about germs. This is religion. I can't touch a man who is not my father, my uncle, my brother. That's why.'"

Thus the nickname. "Mrs. Noof Not Shaking Hands," Noof said, and laughed so hard that she almost fell over on the sofa. Noof's laugh, which is rich, is one of the reasons we became friends. She's quick-witted and tough. She makes fun of people who are officious or rude. One of her cell phones rings to music from *Grey's Anatomy*. In her 20s she rejected alternative suitors preferred by her family because she was determined to marry Sami, whom she loved. She estimates that she saw *Titanic* at least ten times when she was a teenager; movie theaters are prohibited in Saudi Arabia, but popular DVDs are easy to come by, no matter what disapproving conservative sheikhs may say. (When I recalled that *Titanic* includes an enthusiastic sex scene featuring the not-yet-married heroine, Noof was unruffled. "Yeah, it's OK," she said. "It's her culture.")

I tell you these things here because Sami was about to drive us to the mall so Noof could help me pick out a new abaya, the ankle-length covering garment women must wear in Saudi Arabia, and I want you to see her before she goes to the bedroom closet for one of her own, all of which are black. Abayas in colors are starting to

Saudi Arabia is the world's most gender-segregated nation, but amid changes now under way, multiple generations of women are debating how to be truly modern and truly Saudi.

SCALE VARIES IN THIS PERSPECTIVE.

proliferate in Jeddah, the less conservative port city in the west, but in Riyadh a nonblack abaya worn in public still invites scowls from strangers and possible rebuke by the street-patrolling religious police. The abaya Noof pulled out had gray plaid trim, with a flashy hint of red in the plaid—Noof had bought it in Jeddah. And pockets, very convenient, a cell phone pocket sewn onto the left sleeve. Noof shrugged the abaya over her skirt and blouse, the way one might don a raincoat. She snapped it down the middle, recasting her outer shape as an elongated black triangle. She wrapped her black *tarha,* the long Arabian head scarf, over her hair and under her chin and once more over her head.

"Where's my purse?" Noof asked. Sami brought it to her. Then, just before crossing the threshold of their apartment building's front gate, Noof draped the remaining length of tarha completely over her face, which vanished, leaving visible only the skin of her ungloved hands. We climbed into their Toyota, Sami and Noof up front, and headed out into the evening to shop.

THE LITANY OF "ONLY NATION IN THE WORLD" rules in Saudi Arabia is familiar by now, partly because it provides such provocative news fodder for disapproving outsiders: The only nation in the world that prohibits women from driving cars. The only nation that requires every adult female citizen to live under the supervision of a legally recognized male guardian, her father or husband or some other family member, who must grant formal permission before she can obtain a passport, complete certain legal matters, or travel abroad. The last nation, other than Vatican City, to grant women the vote; the inaugural registration period was just six months ago, and women who lived more than walking distance from the sign-up sites needed men to chauffeur them there.

In Saudi Arabia all restaurants serving both men and women have divided eating areas, one for "singles," which means men, and one for "families," which means women, plus children and any men in their parties who are close relatives. Men and women not tied by blood or marriage can pretend they are, but risk rousting by religious police; law and social dictates prohibit them from sitting together. Inside shopping mall food courts, where Middle East brands compete alongside McDonald's and KFC, gender partitions doubling as menu signs divide each stall's ordering counter.

All sorts of practical matters, including the physical layout of buildings, are arranged in deference to mandates that Saudi women be segregated from men. When King Abdullah declared in 2011 that he would begin appointing women to the royal advisory council, the

NGM MAPS

Shura, the ensuing national clamor—outrage from conservatives, elation from women's advocates—included serious questions as to how these women could properly be seated. Should they be given separate chambers, with video links to their colleagues? Almost all Saudi schools are single sex, including faculty, and video is how some colleges handle lectures by professors of the wrong gender.

Even the "jobs feminization" campaign to encourage Saudi women to join the labor force, a five-year-old initiative also ordered and championed by Abdullah before his death last year, has come with elaborate segregation rules. After decades of an informal prohibition on women taking jobs that might place them in contact with men, certain kinds of retail stores have been ordered to hire female clerks, and the government is offering incentives for putting Saudi women on the payroll. The female supermarket cashiers, though, are grouped away from the male cashiers. Brand-new interior walls snake through department stores, separating male from female clerks. Every workplace that includes both genders is required to designate a no-men-allowed area where women can feel more "comfortable"—I heard that word from *women,* over and over.

So I would ask: Help me understand. Why is that more comfortable?

And the women's answers almost always started the same way: Well, in the women's area you can take off your abaya, relax, and…

Why can't you take off your abaya in front of the men?

This is when they would regard me levelly for a moment, and then sigh and nod, like, *OK, here we go.*

Because we are Saudi, and inside Saudi Arabia, we don't. That would have been the easiest reply, but no one ever worded it that way; this obligation to hide the female form from nonfamily men, so perplexing and unsettling to outsiders, can be complicated for Saudis too. Nearly every woman who talked to me about covering invoked tradition, social pressure, religious devotion, tribal loyalty, and the primacy Saudi culture places upon respectability, the assurance that a woman's honor—her fidelity and probity, if she's married; her modesty and virginity, if she's not—remains unimpeachable.

Do not imagine that the only enforcers of these standards are men, either. They're mothers, aunts, sisters, female passersby who feel free to chide women they don't know. "Why are you trying to attract men? Cover!" a 25-year-old Riyadh woman recited in frustration for me, mimicking scoldings from strangers. "It's like *she's* covering head to toe and asking other women to be exactly like her."

Because each time I returned to the United States from Saudi Arabia, everybody I knew asked whether I had been forced to wear a burka, some wardrobe clarification may be useful. The Saudi women's covering robe is the abaya—not the chador (Iran) or the burka (Afghanistan). Although very conservative women sometimes wear an over-the-head variation, abayas are generally neck-down garments; think of a judge's robes. Women in public may shed their abayas in and around hospitals, inside certain gated residential areas for foreigners, and on the premises of women-only facilities. (One of the fanciest shopping malls in Riyadh, for example, contains a whole floor strictly for women.) Outside of those places: no. Men wear jeans or suits or the white Arabian robes called *thobes.* Women past adolescence, including expat corporate managers and visiting reporters, wear abayas.

Why black, which absorbs heat, in one of the hottest places on the planet? Speculative explanations abound: because black is unappealing to a man's gaze, or because there's an Islamic scriptural reference to women of the Prophet Muhammad's time wearing clothing that made them resemble black crows. There's no law that specifies abaya color. There's no actual law requiring abayas, for that matter. Four decades ago, older Saudi women told me, protocols for covering and comportment varied across the kingdom, according to region, class, and one's own family and tribal standards. The monarchy was a young nation then—established in 1932,

CELL PHONES UPDATE A VENERABLE PASTIME In winter the Saudi tradition of weekend picnics in the desert—with SUVs, multicourse meals, and dune buggies so the men can roar around on the sand—remains

popular. Three of the five al Basri sisters relax as their children romp on this slope outside Riyadh.
In summer, air-conditioned shopping malls are the public destination most inviting to women and families.

newly flush with oil money, and still a patchwork of Arab cultures, from desert tribes with ancient traditions to cosmopolitan cities along the coasts. Although Islam of an especially conservative and all-consuming form was the faith of the whole country, its expression varied from place to place.

And in certain Saudi regions of that era, older women remember, there was nothing shocking about going out in a casual short abaya or wearing modest clothing with no outer cover at all. "Most of us went without veils," a retired Riyadh pediatrician in her 70s recalled. "Sitting with a man you are not married to, in a restaurant? No problem, as long as you were behaving correctly. And then—the change. Some twisting, I will say. In the mind, in the heart."

The change came in the 1980s, as conservative Islamist movements were burgeoning throughout the Middle East. The Saudi government, its legitimacy threatened by such upheaval, enlisted religious police in a kingdom-wide crackdown that imposed upon all Saudis the rigidity of its most conservative cultures. School curriculum was revamped. Music was silenced as un-Islamic. Couples walking or driving in public together were forced to show police their marriage licenses.

And central to the conservative crusade was the castigation of women: for succumbing to Western influence, for appearing outside the home without male guardians, for speaking in voices that might distract or seduce men, for dishonoring God by failing to drape themselves completely in black. In Arabic, Muslims use the word *awrah* to mean the more private parts of the body, those a respectable person always covers in public. Every society in the world has its own versions of awrah, and the Saudi Arabia of the past few decades has instructed all its faithful to regard as awrah not only a woman's hair, as is widely taught across the Muslim world, but also her calves, her arms, and perhaps—depending—her face.

Saudis were amused by my efforts to grasp this "depending" part; it was like a newcomer to American culture interrogating one woman after another about the rules for displaying cleavage. We veil our faces, they would tell me, when it feels right. When our families follow imams who insist the face is awrah, even though other imams say it isn't. When the boys we knew as children would be titillated and embarrassed to see our adult faces exposed. When the message we want to give off is *respect me,* not *look at me.* Women debate each other about the niqab, which is the word Saudis use for the black, tie-on cloth made specifically for covering the face; I once sat through a table-pounding niqab argument among three Riyadh feminists, one of whom insisted that any modern woman who "chooses" to veil her face does so only under pressure from the oppressive society around her. ("It's NEVER a choice! It is dehumanizing to wear the niqab!" "How can you SAY that?" "NEVER A CHOICE!")

FEMALE, SAUDI, AND FIERCE

Long discouraged from sports, especially those that clerics call masculine, urban women are drawn to clubs and home gyms where they can exercise away from men. Halah Alhamrani, 39, teaches kickboxing at her home in Jeddah; she's a physical trainer, a career that women are taking up despite some hostile response. "Not just men," says another Jeddah trainer. "A lot of closed-minded women see what we're doing as a disgrace."

It was Noof Hassan, in fact, who articulated the pithiest veiling explanation I heard, while she was at work one day and caught me watching her deft adjustments as she entered and exited the women-only factory area. Scarf off face, scarf back over face—Noof glanced at me and said lightly, "This is not something weird for us." Saudi society is still tribal in many ways; women and men alike feel those around them watching, making assumptions about their family standards, passing judgment. *Dayooth* means a man who is not sufficiently vigilant about his wife and other female relatives whose honor he's supposed to be guarding. It is an eviscerating label. "Wimp" does not begin to convey it.

"The problem is how *they* are thinking," Noof said now, from the passenger seat of the Toyota. "This is the issue."

Sami, behind the wheel, said, "When we go out to shop or something, I feel people look at her."

"Staring," Noof said. "Not just looking. Staring."

The most disturbing stares, the ones that rattle Sami, come from men. "So I'm—'Please, Noof, cover your face,'" Sami said. "So he doesn't look to see my wife."

I wondered about the Prophet Muhammad's declaration that men have their own obligation to turn away from temptation and disrespect.

"Yes," Noof said. "Sometimes I'm telling Sami, 'The guy has to stop staring, because this is our religion. Why do *I* have to cover?'"

Sami was quiet, concentrating on the traffic. He's a financial manager. He wears black-rimmed glasses and has a short beard and a gentle countenance. "My answer will be,

Educated and Entering the Workforce

Over the past four decades Saudi Arabia has achieved substantial advances in education for women, most recently under reforms instituted by the late King Abdullah. Although he encouraged women to study and work, the nation still lags behind many other Muslim countries when it comes to employment opportunities for women.

Full Primary School Enrollment

1979
Three out of ten school-age girls were enrolled.

2014
Dramatic growth in oil revenue in the 1970s and '80s enabled the country to build more schools. Today 99 percent of girls attend.

Higher Education Gains

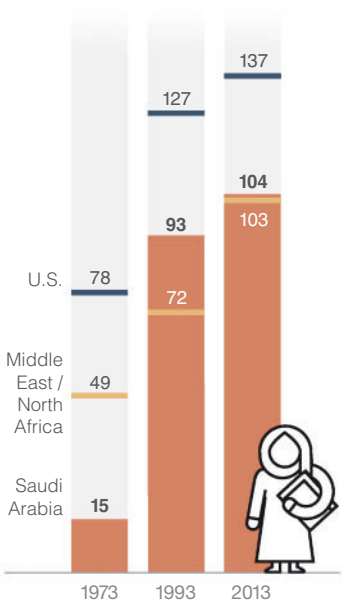
Women now outnumber men at Saudi universities and account for half of all bachelor's and postgraduate degrees.

From University to Employment

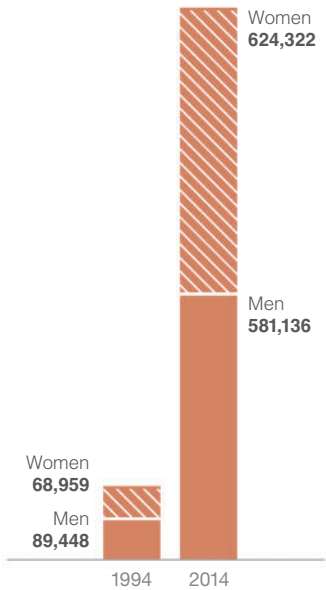
Islamic studies and the humanities are the most popular fields for women and the most likely to lead to jobs in the limited female labor market. Seventy percent of employed women work in education.

STUDENTS ENROLLED

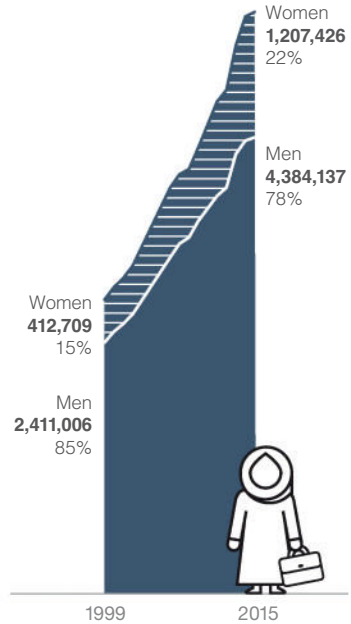
Number of women per 100 men



STUDENTS IN A BACHELOR'S DEGREE PROGRAM



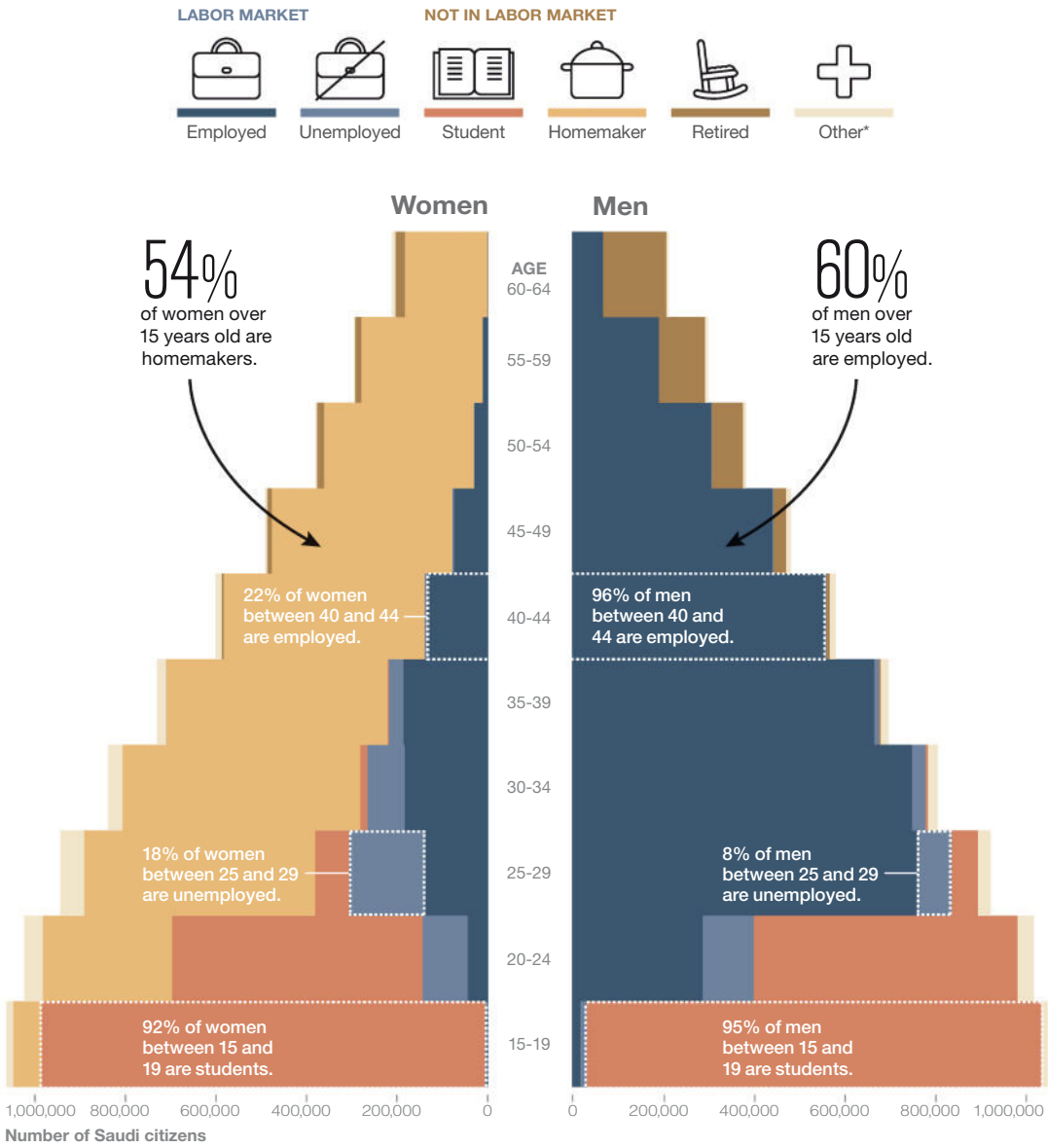
LABOR MARKET



MONICA SERRANO, NGM STAFF; KELSEY NOWAKOWSKI. SOURCES: WORLD BANK; SAUDI ARABIA CENTRAL DEPARTMENT OF STATISTICS AND INFORMATION AND MINISTRY OF EDUCATION

Women at Work

Despite their education, women seeking jobs face many obstacles, including the lack of day care, the inability to drive themselves to work, complex segregation rules, and scarce opportunities in fields such as manufacturing.



Data as of May 2015
*Disabled or unwilling to work

this guy, he's a Muslim, but he doesn't follow Islam in the right way," he said finally. "This man thinks, 'She doesn't cover her face because she likes people to look at her face.' They think like this."

I said that in many societies it was not uncommon for a man, when troubled by the way another man was contemplating his wife, to threaten to punch his lights out.

Sami nodded. He was smiling. "If I fight with the guy," he said, "that means I fight every day."

Noof chuckled. "Too much effort," she said, from behind the black of her scarf. "Look, you can see everything. Try it." I was wearing a tarha and tried to rewrap like Noof: twice around tightly, with the remaining scarf length pulled over my face. The cloth was sheer, evidently woven with this purpose in mind, and outside the car windows things were dimmer and grayer, but visible. A few blocks ahead, a lighted mall hove into view.

I NEEDED A NEW ABAYA because a female Saudi acquaintance with a mordant wit had suggested that the fraying abaya I'd been wearing for weeks might best be retired by burning it. *Emergency shopping help pls,* I texted Noof, and Noof had texted back, *sure my dear.* Now we left Sami to stash the car alongside the other husbands and chauffeurs while Noof led me briskly to the abaya wing, where seven shops stood side by side, a plate-glass-fronted lineup of fluttering, shimmering shades of black.

"Whoa," I said. Noof winked at me. She had rearranged her tarha to half veil—men don't hang around abaya shops much. "I think this

INVISIBLE WALLS ARE EFFECTIVE TOO

With new policies bringing women into some sales jobs, the Families Only sign in this Riyadh mall store tells a lone male shopper he can't come in. For men unaccompanied by wives or children, close contact with female clerks is still unacceptable in much of Saudi Arabia. Detailed rules specify which products must be sold by which gender: no female clerks for men's skin care products, for example, and only women may sell lingerie.

place first," she said, eyeballing one of the entrance doors, and strode in.

An urban Saudi shopping mall can feel like a panoramic stage in which many tiny dramas peculiar to the modern kingdom are all under way at once. Young women window-shop with cell phones pressed to their ears, angling ice-cream cones or soda drink straws into their mouths beneath their niqabs. Pakistani and Filipino drivers nap in the parking lots or video call their overseas families, waiting for the women who employ them to emerge. (How do the drivers figure out which black-veiled lady is which? I once asked a Saudi friend. "Shoes and handbags," she replied.) Inside the relief of reliable air-conditioning are playgrounds, furniture stores, eyeglasses stores, fitness centers, and supermarkets. There's no other nexus of Saudi commerce so steadily populated by women, and after a while I found myself studying passing shoes and handbags, imagining them attached to women I was coming to know: the retired pediatrician, the graphic designer, the market checkout clerk, the business entrepreneur, the sociology professor, the lawyer who plays basketball three nights a week and is six feet tall, with a wicked layup.

That lawyer, a 30-year-old named Aljawharah Fallatah, plays in women-only gyms in girls' schools or health clubs. Why not outdoors, where the young men go? Because that *is* where the young men go, and it would be cumbersome to play good basketball in an abaya. The point, Fallatah reminded me after a practice one evening, is that she's a working attorney in a nation where, until the early 1960s, most girls had nowhere to attend school. A decade ago Saudi women were first allowed to study law. Three years ago the first women received permission to work as lawyers rather than just consultants. Women now make up more than half of the kingdom's university students. When King Abdullah started a royal scholarship program for study abroad in 2005, women were included among its initial scholars; as of 2014, more than 35,000 Saudi women were enrolled in foreign undergraduate and graduate programs, with more than half studying in the United States.

And Fallatah now makes appearances in court. This is not to suggest any sort of parity for male and female professionals; Saudi women with advanced educations complain of underemployment and frustration in a society only beginning to accept females into high-level jobs. That's a familiar lament, though, in nations much older than Saudi Arabia. "What we did in ten years is faster than what women in the United States did in a hundred years," said Nailah Attar, the co-founder of a national initiative called Baladi, which means My Country. "We are running very fast to change very fast. I think we should slow down a little bit—so people accept it."

Attar, along with other female business and academic leaders from around the kingdom, established Baladi five years ago to persuade Saudi

SOMEDAY IT WILL BE JUST A CAR, NOT A FLASH POINT The kingdom's refusal to license women drivers has received so much international press by now that despite ongoing pro-driving campaigns, many women

have soured on the issue. Eventually, they say—on a Saudi timetable—women will be allowed to drive. At a Riyadh luxury goods fair, these women pretend to drive while they pose for photos of themselves.

This obligation to hide the female form from men who are not family, so perplexing and unsettling to outsiders, can be complicated for Saudis too.

women to accept the prospect of voting and running for office themselves. Hostility from traditionalists has been part of their challenge, but so has indifference, even from ambitious women: The first time in nearly a half century that Saudi men voted was in 2005, and the only elected offices are municipal council seats, positions of no authority. The Kingdom of Saudi Arabia is not a constitutional monarchy. There's no separate prime minister, no parliament. Absolute control remains in the hands of the Al Sauds, the now enormous family for whom the nation was named.

"Sometimes we're in the 21st century, and sometimes we're in the 19th," a professional Riyadh woman who has lived abroad told me, sounding both aggrieved and resigned. "And imagine yourself in the European Middle Ages, with the Catholic Church." She meant that in Saudi Arabia, dogmatic religious leaders and a royal dynasty still officially share power, to an extent almost unfathomable to people from more secular countries. Insults to Islam or threats to national security—both expediently elastic categories, encompassing blogging, social media, and open defense of the already accused—are among the crimes punishable by imprisonment, flogging, or death. Executions are carried out by public beheading. The organization that runs the religious police (who often operate alongside national police and are authorized to advise, berate, and arrest) is called the Committee for the Promotion of Virtue and the Prevention of Vice.

The conviction that a society's virtue and vice can be managed by keeping men and women apart—that by nature men are lustful and women seductive, so that being a good Muslim requires constant attention to the perils of close contact—is so foundational in daily life that it reappears, for the mystified visitor, in one explanation after another. The reason hotel swimming pools won't admit women or set aside a ladies-only hour: Men might glimpse women's moving shapes in the water. The reason most Saudi clothing stores have no dressing rooms: Women won't take their clothes off with male clerks on the other side of the door. The reason Saudi Arabia has only one movie theater, a new science museum IMAX: The government shut all cinemas during the conservative surge in the 1980s. Besides screening problematic Western movies, dark movie theaters make it easier for men and women to mix.

And the famous prohibition against women drivers? Raising this with Saudi girls and women, I found, elicits an interesting set of reactions, often in the same sequence. First, they say, it is a certainty that Saudi women will be driving sooner or later, despite the thriving subeconomy—taxis, private drivers, the recruiting industry that brings in those drivers from abroad—that feeds off the men-only rules. Some women drive already, in the desert or other areas where no one pays attention; a causeway connects eastern Saudi Arabia to Bahrain, and it's not unusual for Saudi husbands or chauffeurs to exit the driver's seat at the border so the madam can take over.

The second reaction is a sober consideration of the anti-women-driving arguments. The proposition that women would prove unfit behind the wheel and cause accidents—preposterous; the traffic death rate on Saudi highways is a source of national despair. The proposition that women would have affairs and abandon their families if they could leave home whenever

they wished—only the most backward-looking sheikhs still make such claims, replied women I talked with. Abdullah himself urged us into the workplace, they would say. How can we do a proper job if we must rely on others to get us to work on time?

The serious worry, both women and men told me, is for the drivers themselves—the first women who will drive alone, once they are licensed, amid what are sure to be at least some hostile and predatory men. "I have talked to ladies at my factory about this," Noof said. "One told me her brother said, 'If I found any lady driving, I would stop her car and force her to get out.' Many of the men, not educated, that's what I'm thinking about. They write this on the social media. *'We will make you* stop driving the cars.'"

That brother, we wondered—does he plan to protect his sister from harassers, or do the harassing himself? Or both? We flipped through hanging abayas, which I was learning come stretchy and machine washable for power walking or desert picnicking; tastefully embroidered for the workplace or visits to extended family; and gussied up for fancy occasions, with sparkly stones or ruffles or—hello!—peacock feather eyes woven right into the cloth. "No," Noof said firmly, flipping and squinting and fingering. "No. No. No." Then she stopped, her hand on a deep gray sleeve with a black band of satin at the wrist. "OK, see if you like this," Noof said. "Soft."

THE FEMALE MEMBERS OF THE SHURA were sworn in on a February morning in 2013, some with black niqabs or scarves over their faces, others without. The women's seats were in the great council chambers, alongside the men's. "We women were grouped together, it's true," said Thoraya Obaid, a former UN Population Fund director and UN undersecretary general, who is one of the new members. "But there were no walls and no separations. And we were *there.*"

Obaid spent 35 years with the United Nations, but she is by no means the only Shura member with professional credentials and an international education. "Of the 30 of us, 27 have medical degrees or Ph.D.'s," she told me. "Two of us are princesses with long histories of social activism and social work."

The king wanted women of substance, in other words. Inside Saudi Arabia it's not hard to encounter privately voiced anger at the royal family, which maintains unyielding dominion over the kingdom's oil wealth, uses repressive state power to silence any call for representational government, and regularly receives scorching reviews from international human rights organizations. Even so, the mention of Abdullah's name usually made women's faces light up. "I remember his statement in Arabic: *La tahmeesh,* which means, 'No more marginalization,'" recalled Hanan Al-Ahmadi, a government executive who was in the audience when the king announced his intent to include women in the Shura. "Women, including me, had tears in their eyes."

Al-Ahmadi was appointed to the Shura. She and her colleagues have inured themselves to the steady broadsides characterizing the female Shura members as shills for the West, messengers of the devil, and so on; the criticism crescendos whenever the argument over driving resumes. Al-Ahmadi is in favor of licensing women drivers, but like Noof and many other Saudis I talked with, she said the West's fascination with the driving story has created more national defiance than support. *"Khalas,"* Al-Ahmadi said. Enough. "It's been too politicized. Sometimes I go places where there are


KURSAT BAYHAN

Photojournalist **Lynsey Addario** has covered conflicts around the globe, most especially in the Middle East and Africa. Her recent work has focused on Syrian refugees and maternal mortality in Sierra Leone.

What makes these photographs so significant? It is extremely difficult to photograph women in Saudi Arabia. A majority refused to appear in print. We typically see pictures of women in abayas and niqabs, shopping at upscale malls. I wanted to show a nuanced picture of these women's lives.

many women, and somebody comes up to me and says, 'Do you think we *care* that we drive? This is not our main goal.'"

Ask women from any country what the Main Goal is, and answers will fly at you from many directions. So it is in Saudi Arabia, where I've listened and read as women assail the high divorce rate and the divorce system itself (fathers gain custody of all but very young children); the double-standard citizenship rules (gaining citizenship is straightforward for foreign women who marry Saudi men, but almost impossible for foreign men who marry Saudi women); and the treatment of some of the kingdom's new working women (long hours, low pay).

The requirement that every woman live under the guardianship of a designated male comes in for special vitriol too. Officially, a woman is supposed to be able to work, receive medical treatment, or enroll in university without her guardian's permission. But in Saudi Arabia the official law often yields to tradition, individual interpretations of religious obligation, or fear of repercussions from a woman's family. (Some employers won't hire a woman, for example, without her guardian's approval.) And there are men who use their guardianships, many women say, to punish, control, manipulate.

These are brutal but discrete challenges, women kept telling me, to be taken on one by one, and requiring delicate maneuvering in a place where religious faith, family honor, and state power remain so tightly intertwined. Any outsider urging her countrywomen to fling off

PROPELLING HERSELF, PLAID SNEAKERS AND ALL

Young enough to play in public without cover of abaya and head scarf, 12-year-old Lama Mohammed Bolgari navigates the Jeddah seafront. Vigorous national argument about the proper behavior of modern Saudi men and women is shaping her generation. "We've been through a huge transformation," says royal adviser Hanan Al-Ahmadi. "But we need to be able to create this change gradually and maintain our identity."

their niqabs, Al-Ahmadi says—or to demand en masse their own car keys, or to rip down the separation walls—must understand how many Saudi women would be *un*empowered, her word, by disruptions that profound. "Many Saudi families will not allow their daughters to work as saleswomen because the walls are not tall enough," she told me. "So if you want to empower all Saudi girls to have jobs, you have to remove the stigma from these jobs."

Five years, Noof told me: That's how long she believes it will be before Saudi women drive. Not that driving is a thing she urgently cares about. She has no pressing interest in learning how. The ban is just a stupidity for a working woman trying hard to live a modern life while devoted to both her faith and her nationality; even Saudi scholars have acknowledged that there's nothing in the Quran or other sacred texts forbidding women to drive. Noof and Sami share with other relatives a single hired driver, for a thousand-dollar monthly fee—more than many families can afford.

But like a number of women I talked to, Noof said she was relieved that Abdullah never used his royal powers to order the issuing of driver's licenses for women—and that his successor and brother, King Salman bin Abdulaziz, has made no move to do so. "Step by step," Noof said. She likes some of the incremental options being debated, like offering licenses at first only to older married women, whose dignified appearance in the driver's seat might shame harassing hotheads into behaving themselves. "It will happen, I am sure," she said. "But if you allow all women, tomorrow, it will make a huge mess."

I bought the abaya Noof picked out for me. It cost the equivalent of $40 and was elegant, with black snaps to close it down the front, but I didn't switch into it right away because Sami had proposed bowling, and I didn't want my shoe tracks all over the hem. Noof pulled her scarf back over her face. The Riyadh night traffic was wretched. Noof watched Sami drive. She sensed, apparently, that she still needed to convince the foreigner in the backseat that placing her own foot on an accelerator was not the thing she most desired from this life.

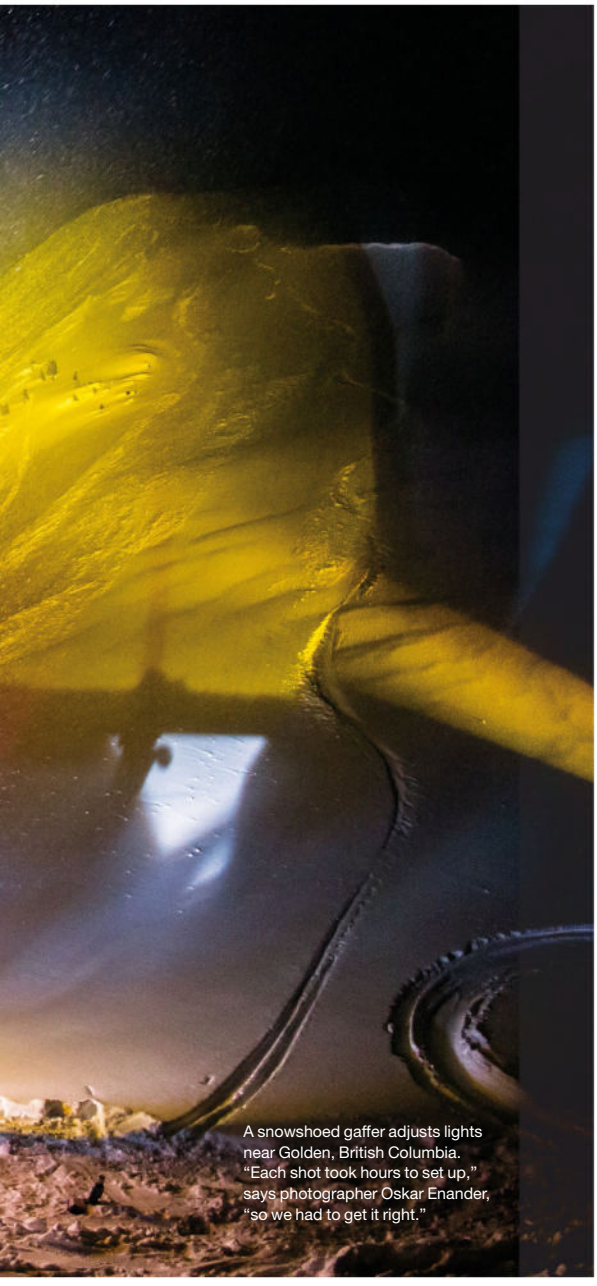
"Huge headache, I'm sorry," she said. "Why should I have to concentrate on the road? I sit here and chat on my mobile, 'OK, we are arrived.' I don't have to search for a parking place."

The bowling alley turned out to be 12 lanes wide. Men in thobes and women in abayas and children were bowling together, at each lane, and against one wall a man and a niqab-veiled woman studied a pool table from multiple angles, taking turns shooting for the corner pocket.

"Of course you must win," Noof said firmly. "Or I would be a bad hostess."

I didn't. The score, though Noof was too good a hostess to say it aloud, was not even close. She knew how to loft a bowling ball behind the folds of her abaya and hurtle it just so, with spin. □

Midnight Slalom



A snowshoed gaffer adjusts lights near Golden, British Columbia. "Each shot took hours to set up," says photographer Oskar Enander, "so we had to get it right."

By **JEREMY BERLIN**
Photographs by **OSKAR ENANDER**

How do you illuminate a mountain, dazzle the snow with colored light, and take nocturnal skiing to vivid new heights?

First, find pristine slopes in the craggy, sylvan backcountry of British Columbia and Alaska. Then, figure out how to get 10,000 pounds of equipment—4,000-watt lights the size of washing machines, generators to power them, scaffolding, wire and cable—up peaks higher than 7,000 feet. Spend months calculating wattage and beam diameters, weights and fuel consumption, distances and topography. Hire skilled gaffers and grips. Enlist a cadre of elite athletes. Put battery packs in their pockets, zip them into light suits, and strap LED-spangled packs on their backs. Turn the camera on. Hope for the best.

That's what Nick Waggoner and his partners at Sweetgrass Productions did in spring 2014, when a commercial shoot gave them the resources they needed to realize a longtime dream: filming night-skiing segments on a big mountain. With Swedish ski photographer Oskar Enander on hand to shoot still photos as they filmed, they set about bringing the dream to life.

"I can't overstate how intense it was to do all this stuff," says Waggoner. "So much of it had never been done before. And we were working in places with incredibly dynamic terrain, some of the deepest snow on Earth, and ever changing weather patterns. Many, many things could go wrong."

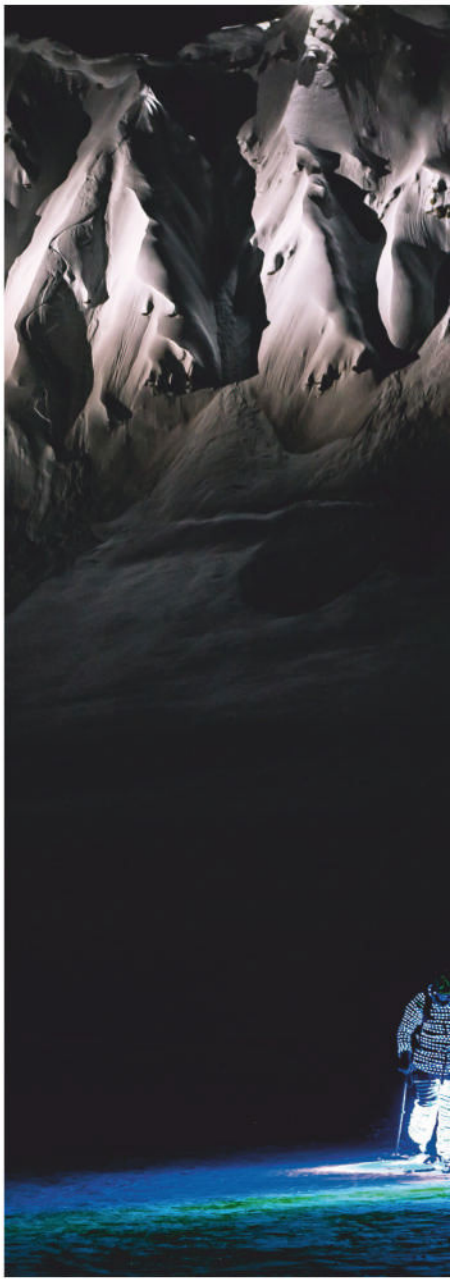
Some of them did. Eleven days into the Alaska shoot, with everything finally in place, a critical extension cord went missing. Waggoner had to persuade a helicopter pilot to fly 20 miles, in the gathering dark, to fetch a new one. "There were times," he says, "when I put my head in my hands and said, 'I'm defeated. I'm lost. How were we this dumb to think this was possible?'"

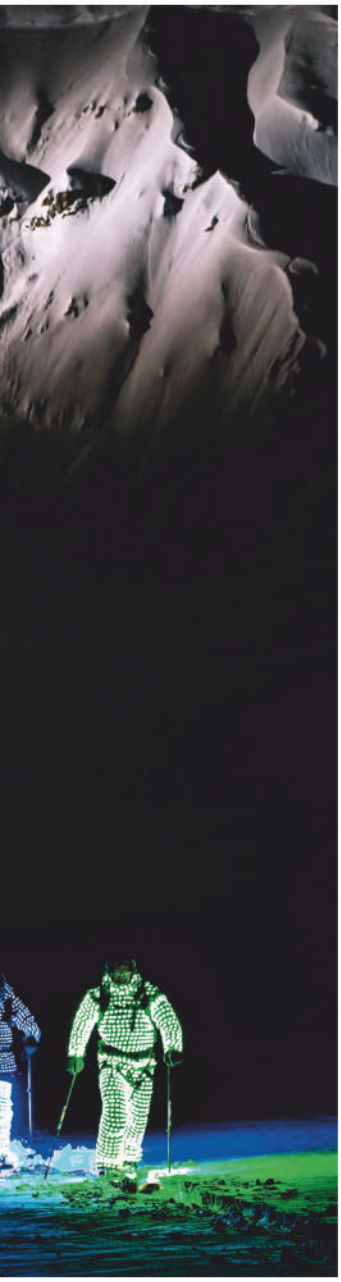
Enander had his own challenges. For one thing, he couldn't use a flash; even a fraction of a second would have disturbed the video shoot. That made it hard to get crisp images. "The biggest hurdle for me," he says, "was shutting out my daylight thinking and focusing on shooting the night."

But in the end, Waggoner says, the dream was realized. "This project is a metaphor for thinking big and doing things you didn't think were possible. We want to give people new eyes to reimagine the world." ◻

NGM MAPS

From left: As the generators shut off in British Columbia, Enander used a long exposure to capture Pep Fujas's progress. Near Anchorage, Alaska, Chris Benchetler and Daron Rahlves light up the night in their LED suits. Before a shoot in British Columbia, Eric Hjorleifson removes nylon strips, used to help climb hills, from his skis.





Over the Rainbow

Long before a party of white explorers laid eyes on it in 1909, the red stone formation in what is now Utah was a sacred site for Navajo, Hopi, Zuni, Paiute, and other native peoples. They came to pray and make offerings under the 290-foot-tall bridge, carved eons ago by coursing water.

In 1910 the U.S. government established the Rainbow Bridge National Monument, with the aim of preserving the natural marvel. For decades tourists could clamber on and around the span, as seen in this 1927 photo by one Hugh Stevens Bell. “Someone is demonstrating that it is perfectly safe to wax acrobatic” atop the bridge, says Bell’s caption.

Whether or not it was safe, or good for the landmark, signs posted by the National Park Service since 1995 have asked tourists not to walk under or onto the bridge, out of respect for the cultural traditions of associated tribes. And the NPS website urges visitors to approach it “as you would a church.” *—Patricia Edmonds*

PHOTO: HUGH STEVENS BELL, NATIONAL GEOGRAPHIC CREATIVE

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